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ELASTOMERIC TANK LIFE EXTENSION STUDIES - Part II

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By

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Time-dependent performances of an epichlorohydrin, a nitrile-based, and three polyurethane-type coated-fabric collapsible fuel tanks were evaluated under sub-tropical outdoor exposure conditions. These five products were filled with a referee grade diesel fuel and a JP-5/JP-8 ST special test turbine fuel. Data obtained from the fuel-filled tanks were compared to those of empty, fuel-free control products.

Results indicated that all examined polyurethane tanks were substantially inferior to those fabricated from an epichlorohydrin or a nitrile product, with the later coated-fabric material being superior.

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EXECUTIVE SUMMARY

Objective: The objective of this effort is to investigate the effects of middle distillate fuels and the environment on fully formulated, unused, and unprotected collapsible fuel tanks.

Technical Approach: A variety of elastomer-coated fabrics and respective seam sections of collapsible fuel tanks, containing two different types of middle distillate fuels, were exposed to subtropical environment for an extended period of time. Selected physical properties of small sacrificial pillow tanks were monitored as a function of exposure time and fuel type.

Military Impact: This comparative study of a variety of coated-fabric compositions identified fuel tank materials that yield increased service life of collapsible fuel tanks and alleviate contamination of fuels and the environment in a cost-effective manner.

Accomplishments: A comparative outdoor exposure study was conducted using five candidate coated-fabric collapsible fuel tank materials in the presence of a referee grade diesel fuel (MIL-F-46162C) and a special test turbine fuel (JP-5/JP-8 ST of MIL-T-5624R). The candidate tanks included three polyurethane products, an epichlorohydrin product, and a nitrile rubber product. Studies included the use of small sacrificial pillow tanks for physical measurements and 1,900-liter (500-gallon) capacity minitanks, manufactured according to MIL-T-52983 specifications.

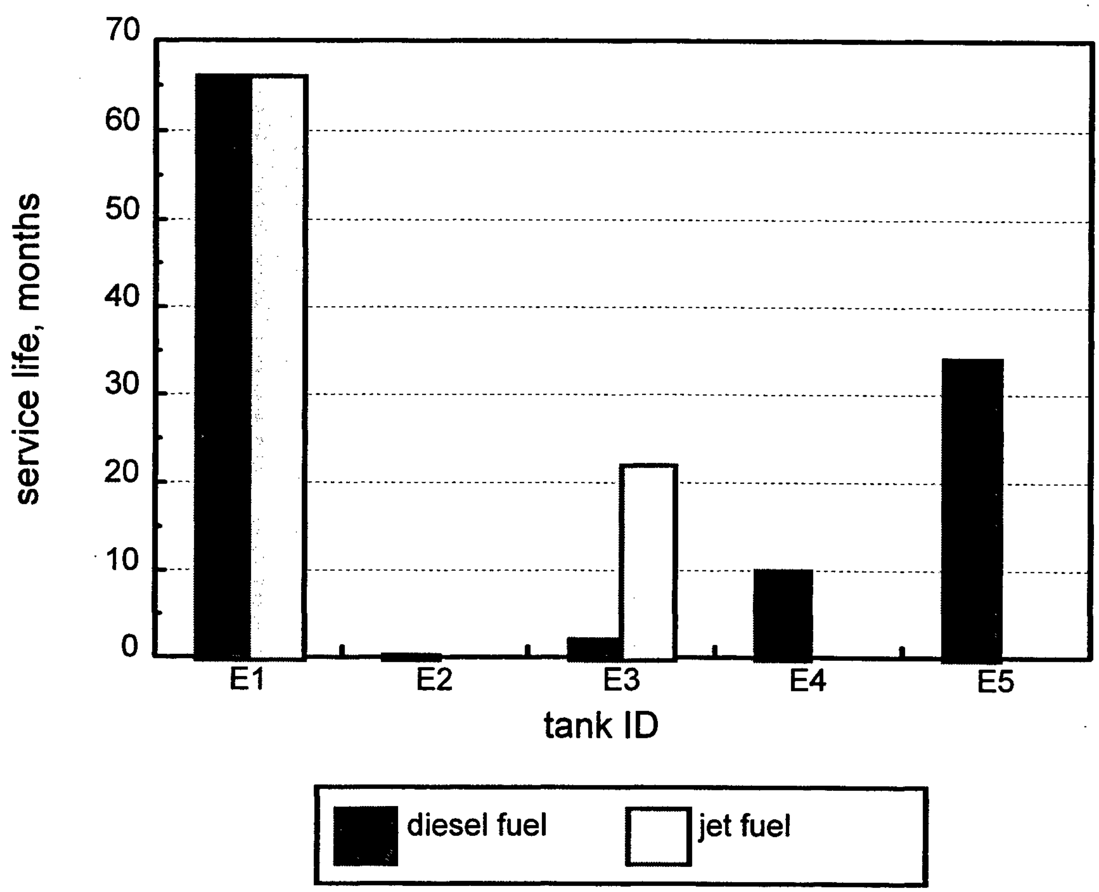
All products were tested with diesel fuel. The nitrile (E-1) and polyester polyurethane (E-3) products were also tested with turbine fuel. All minitanks were to be pressurized to 60 pounds per inch of seam stress to simulate stresses encountered in fuel tanks with capacities up to 50,000 gallons. Upon filling the minitanks, only the nitrile and epichlorohydrin tanks could be pressurized. The seams of the three polyurethane-based tanks leaked excessively upon application of pressure. Therefore, they were not pressurized.

The pressurized E-1 product survived outdoor exposure beyond the 66-month test limit without undue signs of degradation. Testing on the pressurized epichlorohydrin tank (E-5) was stopped after 34 months of exposure because it developed a pinhole while concurrently exhibiting fishscale-type blemishes, signs of impending delamination of the coating from the supporting fabric base. The three various unpressurized polyurethane tanks showed inferior performance compared to these products. The polyester-polyether polyurethane minitank (E-2) failed 24 hours after it was filled with diesel fuel. The E-3 product, which represented the tanks most widely

used by the Army, lasted two months when filled with the referee grade diesel fuel, and 22 months when filled with turbine fuel. The polyether polyester tank (E-4) lasted 10 months when tested against diesel fuel.

The studied polyurethane products are substantially less compatible with the selected fuels than either the nitrile or the epichlorohydrin products. The following barchart summarizes the observations on diesel and turbine fuel-containing, 500-gallon capacity minitanks, illustrating the expected service lives of these products.

Expected Service Life of Candidate Coated-Fabric Fuel Tanks



Note: All coated-fabric tanks were tested with diesel fuel, but only E-1 and E-3 were also tested with jet fuel.

FOREWORD AND ACKNOWLEDGMENTS

This work was performed at the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, TX, from March 1990 to June 1997 under Contract Nos. DAAK70-87-C-0043 and DAAK70-92-C-0059. The work was funded by the U.S. Army TARDEC, Petroleum and Water Business Area, Warren, MI. T.C. Bowen (AMSTA RBFF), L. Turnipseed (AMSTA TR-D/210) and T. Bagwell (AMSTA TR-D/210) served as the contracting officer's representatives and technical monitors.

This report is a continuation of Interim Report TFLRF No. 312, entitled "Coated-Fabric Tank Life Extension Studies," summarizing data collected from March 1990 to April 1996. The present report includes all information provided in that report augmented by those data and observations collected between April 1996 and May 1997, the termination date of this study.

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I. INTRODUCTION

The requirements for rapid, temporary deployment of water and mobility fuels for military field applications are conveniently satisfied by the use of transportable coated-fabric collapsible tanks. While the primary consideration for selection of these products is the suitability of their components for the inert storage of the intended liquids, procurement factors include evaluation of the longevity, weight, and cost effectiveness of these fuel tanks. Past field observations often resulted in conflicting conclusions. The goals of this study were (a) to comparatively evaluate selected, currently available or candidate coated-fabric products and (b) to estimate their useful life in fuel containment.

II. OBJECTIVE

The objective of this project was to evaluate the effects of long-term exposure on unprotected coated-fabric collapsible fuel tank fabric and seam samples in a natural subtropical environment. Through these studies, we evaluated the time dependence of seam and coated-fabric degradation, emphasizing the evaluation of the seam sections' integrity. Data were obtained by performing physical measurements on small sacrificial pillow tanks, augmented by visual observation of fully functional, 1,900-L (500-gal) capacity minitanks.

III. PRELIMINARY SCREENING EXPERIMENTS

To evaluate fuel-elastomer compatibility, an accelerated preliminary study was conducted on five selected products (identified on page 3) by exposing them to four different middle distillate fuels and a middle distillate fuel simulant for 14 days at 80°C.

Guidelines and specifications for this study were established in a Statement of Work.[1] These specifications were partially modified in a subsequent letter[2] for the evaluation of candidate coated-fabric collapsible tank materials for the prescreening experiments, as summarized in Table 1 of Appendix A.

The accelerated preliminary tests on coated fabrics included replicate measurements of tear and breaking strengths in both the warp and fill directions and replicate determinations of diffusion rates of diesel and jet fuels through the fabrics. Screening of seam samples were restricted to confirmation that the samples met specification requirements in regard to their breaking strength and peel adhesion. The averaged results of these experiments are summarized in Table 2.

Preliminary screening experiments, reported in Interim Report BFLRF No. 231 during July 1989[3], indicated that all but two of the five candidate elastomers passed the specification requirements by a wide margin. The average value for peel adhesion of the seam section of elastomer E-3 was found to be 28 lbs/inch, marginally failing to meet the required 30 lbs/inch value. The corresponding average value for elastomer E-5 was found to be 13 lbs/inch, substantially failing this test. It was also noted that in selecting a collapsible tank material, it is important to consider not only the structural integrity of the elastomeric material but also the possible effects of these materials on the products that may be stored in them. Some of the test fuels in the study became grossly contaminated by components of the tank material.

After reviewing the results of the preliminary screening experiments, AMSTA-RBWH of the Mobility Technology Center-Belvoir (MTCB), Ft. Belvoir, VA (now under TARDEC as AMSTA-TR-R/210) accepted all five of these previously selected coated-fabric collapsible fuel tank material candidates for the long-term outdoor exposure tests. The U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, TX, then issued purchase requisitions for the required sacrificial pillow tanks and 1,900-L (500-gal) capacity minitanks to begin the main study of this program.

IV. TEST PROTOCOL AND SELECTION OF CANDIDATE PRODUCTS

Requirements of the accelerated prescreening experiments for the long-term exposure studies were reduced to testing seam sections for their breaking strength and peel adhesion only.[2] An ensuing letter[4] expanded these requirements to include determination of the breaking strength of the coated-

fabric material itself. The same letter also reduced the criteria for failure of the seam sections from 500 to 300 lbs/inch of breaking strength and from 30 to 20 lbs/inch of peel adhesion.

AMSTA-RBWH of MTCB selected five candidate coated-fabric collapsible tank materials for the study. To preserve confidentiality, the manufacturers of the selected materials are not disclosed in this report. The five coated-fabric materials selected for this study are coded as E-1 through E-5, generically identified as follows:

code	coating material	fabric material
E-1	nitrile	nylon
E-2	outer coating: polyether polyurethane	
	inner coating: polyester polyurethane	nylon
E-3	polyester polyurethane	nylon
E-4	polyether polyurethane	nylon
E-5	epichlorohydrin	nylon

Long-term compatibility of candidate products with middle distillate fuels was studied using a referee grade diesel fuel and a special test turbine fuel meeting MIL-F-46162C and JP-5/JP-8 ST of MIL-T-5624N specifications, respectively. In addition, the diesel fuel was procured to contain the MIL-S-53021 stabilizer additive package and 0.8 vol% of ethylene glycol monomethyl ether (EGME), a fuel system icing inhibitor (FSII). Analytical data on these fuels are summarized in Table 3. Both fuels met their target specifications, including the high sulfur content of the referee grade diesel fuel. Note in Table 3 the high concentration of aromatic hydrocarbons present in the diesel fuel.

V. EXPERIMENTAL

Evaluation of the elastomers was performed in two parallel ways. To provide periodic samples for physical testing of seam sections, small sacrificial pillow tanks were procured from the suppliers. These tanks measure approximately 30 x 60 cm (12 x 24 inches) with a seam in the middle of the 60-cm long upper section. From each of the five elastomers, three sets of pillow tanks were placed

under outdoor exposure conditions: one set of empty control or blank tanks, one set containing the JP-5/JP-8 ST turbine fuel, and one set containing the referee grade diesel fuel. The appropriate sacrificial pillow tanks were filled with approximately 10 L of fuel. Air was expelled from the ullage, and the tanks were sealed using fittings installed by the manufacturers. Thus prepared, all internal parts of these tanks, including the entire area of the seam, were in contact with the fuel. The outside surfaces were exposed to the elements. At each sampling period, one sacrificial tank was retrieved from each elastomer set for physical property measurements according to the procedures specified in Table 1. Physical property measurements were made using a SINTECH Materials Testing Workstation, Model 20-G.

Minitanks, with nominal capacity of 1,900-L (500 gal), served as the baseline for overall visual observation and comparison with measured data from the sacrificial pillow tanks. All procured tanks were to be constructed to conform to MIL-T-52983 specifications.

It was planned that all minitanks would be pressurized to 60 lbs/in of seam to simulate seam stresses encountered in fuel tanks with capacities up to 190 cubic meters (50,000 gallons). Pressurization was accomplished using an individual self-compensating, fuel-filled standpipe system for each minitank to alleviate thermally induced pressure fluctuations in the fuel tanks. For each minitank, the standpipe system comprised an individual fuel reservoir, a solar-powered pump, an overflow drain to the standpipe, a safety pressure relief valve, and a pressure gauge. As the fuel expanded due to increased ambient temperatures, the excess fuel in the standpipe returned to the fuel reservoir. During fuel contraction, a float switch located near the top of the standpipe activated the pump, returning fuel from the reservoir into the tank to push the fuel level in the standpipe to the desired height.

According to instructions by AMSTA-RBWH, two E-1 and E-3 minitanks were procured to test their compatibility with jet and diesel fuel. Single minitanks made of E-2, E-4, and E-5 were procured to be tested with diesel fuel only. Upon filling the minitanks, it was noted that only E-1 and E-5 minitanks could be pressurized, while the polyurethane-based E-2, E-3, and E-4 minitanks started to leak excessively through their seam sections upon application of pressure (discussed later).

With concurrence by AMSTA-RBWH, these tanks were tested using the less stringent experimental conditions by filling them with fuel only to zero head pressure.

VI. DISCUSSION

During the outdoor exposure experiments, the 1,900-L minitanks were used as a comparative baseline for non-intrusive visual observations only. Physical measurements were performed on the sacrificial pillow tanks. Seam samples were tested using specially manufactured, small pillow tanks having capacities of approximately two gallons. One control sample, and one each of those samples containing diesel and jet fuel, were sacrificed during each sampling period. Evaluation of sample integrity included physical testing to determine changes in seam breaking strength and peel adhesion. During the last two years of the study, the breaking strengths of the coated fabrics were also measured.[4]

Project plans specified the following test matrix for the 1,900-L (500-gal) minitanks:

elastomer ID	blank	jet fuel	diesel fuel
E-1	no	yes	yes
E-2	no	no	yes
E-3	no	yes	yes
E-4	no	no	yes
E-5	no	no	yes

The matrix of the specified sacrificial pillow tanks included all five coated-fabric compositions against both fuels, with the empty tanks providing the baseline or control (blank) values:

elastomer ID	blank	jet fuel	diesel fuel
E-1	yes	yes	yes
E-2	yes	yes	yes
E-3	yes	yes	yes
E-4	yes	yes	yes
E-5	yes	yes	yes

A. <u>Long-term outdoor exposure experiments using 500-gal. minitanks</u>

The outdoor experiments using the 1,900-L (500-gal) capacity minitanks may be summarized as follows:

E-1 minitanks were filled with the referee grade diesel fuel and JP-5/JP-8 ST turbine fuel, and pressurized to 60 lbs/inch seam stress after a two-week observation period. After seven months of outdoor exposure, these products were depressurized and emptied so that the manufacturer could repair leaking O-rings. The tanks were out of service for two months, then refilled and pressurized. Except for some minor fuel-related surface discolorations, these tanks are still under test conditions after more than 66 months of outdoor exposure. The fabric of E-1 is smooth, with several visible 10- to 15-cm diameter, fuel-induced discolorations. Photographs 1 and 2 in Appendix C show the initial condition of the diesel and turbine fuel-filled minitanks, respectively. Photograph 3 was taken after these tanks were under pressurized test conditions for 53 months. The appearance of both of these tanks are essentially identical to those depicted on Photograph 3, even after 66 months of exposure.

E-2-, E-3-, and E-4-derived minitanks leaked extensively at several spots from their seam sections while being filled with fuel. These tanks were returned to the fabricator for repair or replacement (at their option). The returned tanks were refilled with fuel. Again, these tanks were filled only to their capacity, but due to extensive leakage at seam sections, none of them could be pressurized.

E-2minitank began to display signs of approaching failure immediately after being filled with diesel fuel, as shown in Photograph 4. All the seams were flooded with fuel, and there were several blisters in the seam sections. Leaks were clearly evident at all four corners. Patches of fuel appeared along the perimeter of the tank on top of the berm liner. To alleviate the safety and environmental hazards, the tank was surrounded by "Hazorb" spill-control pillows to soak up the puddles of fuel along the periphery of the tank. (These spill-control pillows, replaced as needed around the tanks, are filled with inert foamed sand designed to adsorb acidic, caustic, solvent and oil spills.) Photograph 5

shows the soiled spill-control pillows around this minitank. Twenty-four hours later, a stream of diesel fuel was found escaping from this tank, as seen in Photograph 6. The tank was emptied to avoid environmental and safety hazards.

E-3 minitank is shown in Photograph 7 immediately after it was filled with diesel fuel. Within two months of storage, this tank had to be emptied and withdrawn from further testing due to excessive fuel leakage at seam areas. Photograph 8 illustrates one such area. The minitank of E-3 is shown in Photograph 9 one day after it was filled with turbine fuel. Except for minor leaks from the seam areas, this tank survived 22 months of outdoor exposure before it also had to be emptied of fuel due to an over 100-cm long, fully separated seam section, as shown in Photograph 10. The empty tank was allowed to remain at the test site. One year after this picture was taken, most of the upper surface of this tank suffered from environmentally induced, major delamination of the coating material from the nylon fabric, demonstrating full degradation of this material, as shown in Photograph 11.

E-4 minitank, filled with the referee grade diesel fuel, is shown in Photograph 12. This tank failed after 10 months of exposure and had to be taken out of service due to excessive leaking from seam and corner areas, as shown in Photograph 13. Note the severe darkening of the outer surfaces of this tank.

E-5 minitank was filled with diesel fuel and pressurized using the standpipe system. Photograph 14 was taken within one week after this tank was placed under test conditions. After approximately 34 months under full test conditions, a pinhole developed in the fabric at the upper part of the minitank. Due to the internal pressure, a very small stream of fuel began to spray to a height of 12 to 15 cm (5 to 6 in.). Even after approximately 265 L (70 gal.) of diesel fuel was removed from the tank, the fuel kept oozing from the pinhole. Concurrently, 1- to 2-mm diameter, fish-scale type blemishes were also observed over the entire surface of the minitank, indicating delamination of the elastomeric coating from the supporting fabric. The condition of this tank and the escaping large quantities of diesel fuel are shown in Photograph 15. Due to the imminent failure of this minitank, for safety and environmental concerns, and because of the excessive cost of potential cleanup, the diesel fuel was withdrawn from the tank.

B. Visual observations during long-term outdoor exposure of sacrificial pillow tanks

Some of the polyurethane-type sacrificial pillow tanks exhibited fuel compatibility problems within one year of exposure, closely resembling the behavior of the larger minitanks. When filled with diesel fuel for one year, 7 of 36 tanks showed fuel leaks along seams of E-2 pillow tanks. Of the 36 E-2 pillow tanks filled with jet fuel, nine leaked fuel through the seams. One of these tanks leaked all its fuel to the berm liner.

When filled with diesel fuel, only 1 of 36 tanks had a minor fuel leak along the seam of the E-3 pillow tanks. The same material containing jet fuel similarly developed a fuel leak in 1 of 36 pillow tanks.

Fuel leaks were found at the seams in 18 of 36 pillow tanks made of E-4 when filled with diesel fuel. The majority of these pillow tanks (33 of 36) developed jet fuel leaks as well within a month after they were filled.

During the same 12-month period, and during the succeeding 54 months, pillow tanks made of E-1 and E-5 showed no signs of similar distress when containing either diesel or jet fuels.

After outdoor storage for approximately 20 to 22 months, the polyurethane-coated sacrificial pillow tanks that contained referee grade diesel fuel were found to be severely degraded. Within approximately one week several small streams of diesel fuel were observed on the previously clean berm liner. Further investigation revealed that most of these small pillow tanks were empty. Those that still contained diesel fuel split at the seams and spilled diesel fuel onto the berm liner when an attempt was made to gently lift them by hand. These observations were expected to occur after examining data from earlier breaking strength and peel adhesion measurements.

At the same time, it was also observed that the polyurethane pillow tanks containing JP-5/JP-8 ST fuel were essentially (but not fully) empty. All of these pillow tanks were refilled with approximately 1 gal. of the fuel and returned to testing conditions.

The visual observations are documented in photographs 16-21. Photographs 16-18 show the newly deployed (a) empty control or blank tanks, (b) turbine fuel-filled tanks, and (c) diesel fuel-filled sacrificial pillow tanks, respectively. Photographs 19-21 show the same set of sacrificial pillow tanks approximately two years after deployment. Three of the diesel fuel-containing E-2 minitanks exhibited major delamination of the coating polymer from the nylon fabric. One such pillow tank is pictured in Photograph 22.

VII. PHYSICAL PROPERTY MEASUREMENTS ON SEAM SECTIONS

Physical property measurements were performed on the periodically retrieved sacrificial pillow tanks according to the procedures specified in Table 1. Required seam breaking strength and seam peel adhesion limits were set at 500 and 30 lb/in., respectively.[2]

Data are presented in both tabular and graphical forms. To provide a ready comparison of each of the five individual types of sacrificial pillow tanks, data with graphical illustrations are furnished for all five elastomers for outdoor exposure periods of 6, 12, 18, 24, 30, 36, 42, 48, and 54 months as measured by the breaking strength and peel adhesion of the respective seam sections. Additionally, breaking strength and peel adhesion data as a function of outdoor exposure time are also given for each of the five individual types of sacrificial pillow tanks for the control (blank), the jet fuel-, and diesel fuel-containing specimens.

Tables 4-8 contain all measured breaking strength and peel adhesion data obtained on the seam sections of E-1 for exposure periods of up to 66 months, and those for E-2 through E-5 for exposure periods of up to 54 months. The data include triplicate raw measured values and the average and standard deviation of the data on the control (blank, fuel-free) pillow tanks and those that contained either the JP-5/JP-8 ST turbine fuel or the referee grade diesel fuel. Also presented are the changes in these data, expressed as a percentage of the control values. Tables 9 and 10 summarize the average and standard deviation of data (from Tables 4-8) as a function of coated-fabric composition at constant exposure periods, and as a function of exposure time for each composition, respectively.

The comparative performance of each coated-fabric composition at identical exposure periods (Table 9) show, in contrast to E-1 (nitrile) and E-5 (epichlorohydrin), the limited useful life-cycles of E-2 through E-4, the polyurethane products. While all products approach specification requirements after six months of outdoor exposure, after 12-months of exposure the peel adhesion values for the diesel fuel-containing polyurethane tanks failed to meet their specifications.

Graphical illustrations of seam breaking strength and seam peel adhesion data, summarized from Tables 9 and 10, are shown in Figures 1-28 in Appendix B. Figures 1-9 show the comparable seam breaking strength data for E-1 through E-5 after 6, 12, 18, 24, 30, 36, 42, 48, and 54 months of outdoor exposure, respectively, of the fuel-free blank (control) samples and those that contained either turbine or diesel fuel. Corresponding, combined peel adhesion data are shown for E-1 through E-5 in Figures 10-18, respectively.

The changes in seam section breaking strengths as a function of outdoor exposure of E-1 through E-5 are shown in Figures 19-23, while corresponding changes in the peel adhesion are given in Figures 24-28.

Examination of individually measured data tabulated in Tables 4-9 and in Figures 1-28 reveal occasional, large sample-to-sample variations in seam-section properties. It may be argued that such variations were caused by manufacturing problems associated with such small pillow tanks. Similarly, apparent "reversals" in physical properties as a function of time may have been caused by the same difficulties.

Several general comments can be made. Measured data on sacrificial pillow tanks support findings of visual observations. Examination of the exposure time-dependence of the breaking strength and peel adhesion data for the seam sections of the individual coated-fabric tanks shows the following trends:

During breaking strength measurements, most failures occurred in the fabric, rather than the seam sections. All specimens of E-1 broke in the fabric, while E-5 gave variable results. In case of the

blank (control) specimen, all failures took place in the fabrics.

Breaking strength changes in the seam sections of E-1 (Figure 19) showed that most of the average of measured data was below the required 500 lb/in. value, but all data remained above 300 lb/in. for the entire reported 66 months of outdoor exposure. Peel adhesion values (Figure 24) of this product remained above the specified 30 lb/in., except for the jet fuel related data obtained at 36 months of exposure, a possible specimen defect.

E-2 containing diesel fuel showed degraded breaking strength at 12 months of exposure and complete failure between 24 and 30 months (Figure 20). Breaking strength of the seam sections of tanks that contained turbine fuel dropped to below 300 lb/in. after 30 months of exposure. Peel adhesion values (Figure 25) of the 12-month samples were found to be below 20 lb/in.

E-3 yielded breaking strength data (Figure 21) above 500 lb/in. for the six-month sample. The 12-month sample containing diesel fuel gave a breaking strength of approximately 300 lb/in. and subsequently yielded incrementally reduced values. The 24-month sample exhibited almost zero breaking strength. Peel adhesion data (Figure 26) gave a similar trend.

E-4 delivered similar results to those of E-3 (Figures 22 and 27). Breaking strength data on the diesel fuel-containing pillow tanks dropped to below 300 lb/in. after 12 months of exposure, and to about 50 lb/in. after 18 months. In the presence of turbine fuel, these tanks gave seam breaking strength data above 400 lb/in. to 24 months of exposure, but exhibited subsequent rapid degradation. In the presence of diesel fuel, peel adhesion data dropped to below 30 lb/in. during the first 6 months of storage, and to 10 lb/in. after 12 months. In presence of turbine fuel, peel adhesion data remained excellent for 18 months of storage, rapidly degrading subsequently.

Breaking strength measurements of the seam sections of the sacrificial pillow tanks of E-5 gave close to the specification values for up to the reported exposure limit of 54 months, as shown in Figure 23. However, measured peel adhesion data (Figure 28) have always exhibited marginal to failing values.

VIII. PHYSICAL PROPERTY MEASUREMENTS ON FABRIC SECTIONS

To fulfill new requirements defined in a letter by AMSTA-RBWH during March 1995,[4] breaking strength data were also collected on the coated fabrics during the last two years of this study. Specification limit for breaking strength of the coated fabric was reduced from 500 lb/in., as stated in Table 1, to 300 lb/in.[4] To further satisfy the new requirements, breaking strengths of the coated fabrics were measured in both warp and fill directions.

Breaking strength data were collected on the E-1 specimen after 42, 48, 54, 60, and 66 months of outdoor exposure. Corresponding data were collected on E-2 to E-4 specimens after 30, 36, 42, 48, and 54 months of exposure. The measured values for the unexposed, new products were measured during the preliminary phase of this work. To provide baseline reference values, the data from the preliminary study[3] are also included in these tables under the heading of new products, corresponding to zero exposure period.

The measured replicate data, their average value, and associated standard deviations are given in Table 11. The data include results of breaking strength measurements in both the fill and warp directions on the blank (fuel-free) specimen and those that contained either the referee grade diesel fuel or the turbine fuel. The averages and sample standard deviations of these data are compiled as a function of composition after identical exposure periods (Table 12) and as a function of exposure time for each composition (Table 13). A lack of entry in these tables indicate that either not enough replicate measurements were made to provide standard deviation for the data (from the preliminary data set), or that the samples were degraded to such an extent that no measurements could be made on them.

Breaking strength data in the fill direction from Tables 12 and 13 are graphically presented in Figures 29-39. Figure 29 shows the results of breaking strength measurements on all five of the unexposed, new products. Note that the breaking strength of each product was substantially above the 500 lb/in. specification values. Figures 30-34 show the breaking strength values (in the fill

direction) for the fabric sections for each of the five products, corresponding to exposure periods of 30, 36, 42, 48, and 54 months. Note that there are no data available for E-1 for the 30 and 36 month exposures, because E-1 had already been exposed to the elements for 42 months when these measurements were initiated.

Figure 30 shows the compatibility of the fabric sections of E-2 through E-5 after 30 months of exposure for the blank, the turbine and the diesel fuel-containing sacrificial pillow tanks. Among these products, only E-5 shows resistance toward both the diesel and turbine fuels, and E-2 toward the turbine fuel only. The fabric sections of E-3 and E-4 show marginal breaking strength when in contact with turbine fuel, and full failure when containing diesel fuel.

Figure 31 indicates that in comparing the fabric sections of E-2 through E-5, only E-5 meets the 500 lb/in. specification requirements in the presence of the test fuels. Figures 32-34 show the comparison of the breaking strengths of the fabrics of E-1 through E-5 after exposure periods of 42, 48, and 54 months. It is common in all these charts that samples of E-3 and E-4 are useless in the presence of these fuels, while specimens of E-5 exhibit consistently superior performance. After 42 months of exposure, E-2 still provided measurable breaking strength in contact with the turbine fuel. The failing measured values for the blank and turbine fuel-containing E-1 specimen after 42 months (Figure 32) seems to be anomalous, especially when compared with the results obtained after 48 and 54 months of exposure, as indicated in Figures 33 and 34. These last two charts indicate that only E-1 and E-5 meet the specification values of 500 lb/in. at the termination of these studies.

Figures 35-39 show the time-dependent changes in the breaking strengths of E-1 through E-5, respectively. These figures show comparative breaking strength values for the new, unexposed blank specimen, as measured during the preliminary phase of this study. Figure 35 shows that, except for the apparently anomalous observations after 42 months of exposure, E-1 meets the 500 lb/in. specification values. While meeting specification values when containing turbine fuel for 30 months, the failure of E-2 to contain diesel fuel is evident in Figure 36. Figures 37 and 38 show the historical behavior of E-3 and E-4. While the fabric of E-3 shows breaking strengths in excess of

300 lbs/in. in presence of turbine fuel for up to 36 months, this product's incompatibility with diesel fuel for the indicated exposure times is evident. The fabric section of E-4 marginally meets specification breaking strength in the presence of turbine fuel for up to 30 months of exposure, but, due to prior degradation, corresponding diesel fuel-containing E-4 samples were no longer available. Figure 39 shows that E-5 meets the specification requirements in the presence of either fuel.

Performance of the fuel-free control samples also indicate the storage life of exposed new tanks. Figures 40 and 41 illustrate the comparative seam breaking strength and peel adhesion of these products during 54 months of outdoor exposure. As shown, all control samples met the 500 lbs/in. breaking strength criterion. Peel adhesion data show large sample-to-sample variation possibly due to fabrication difficulties. Decreasing peel adhesion values were noted for E-4, while all E-5 samples failed the 30 lbs/in. peel adhesion limit.

IX. EFFECTS OF ELASTOMERS ON THE CONTAINED FUELS

Steam jet gum is a fuel quality indicator, measured according to the procedures in ASTM D 381.[5] This parameter provides data reflecting the presence and quantities of fuel-soluble products of low volatility, *e.g.*, fuel-degradation products or possible low-volatility, dissolved foreign products, such as those that may have been dissolved from the fuel's container. Steam jet gum values above 20 mg/100 mL usually may imply high levels of contamination or degradation of the fuel. As a cursory, peripheral study, fuel samples were recovered from the small, sacrificial pillow tanks to evaluate their steam jet gum contents to discover possible deleterious effects of the elastomers on the fuels. No attempt was made to identify the source(s) or components of the gums.

Steam jet gum data collected during the life of this project are summarized in Table 14. Data from Table 14 are also shown graphically in Figures 42-46 for E-1 through E-5, respectively. The observations may be summarized as follows:

1. Fuel contamination in the referee grade diesel fuel is shown to be higher than in the JP-5/JP-8 ST fuel. Contamination of the JP-5/JP-8 ST fuel by the various elastomers generally parallels that of the diesel fuel, but at reduced levels, *i.e.*, the examined products were more resistant to turbine fuel than to diesel fuel. These observations are in agreement with results of the physical property testing. A possible reason for this phenomenon may be higher aromatic hydrocarbon content of the diesel fuel.

2. Fuel samples were available throughout the full exposure period only from E-1 (66 months) and E-5 (54 months), as shown in Figures 40 and 44. Pillow tanks prepared from E-2, E-3, and E-4 disintegrated at intermediate times, as indicated in Figures 41-44.

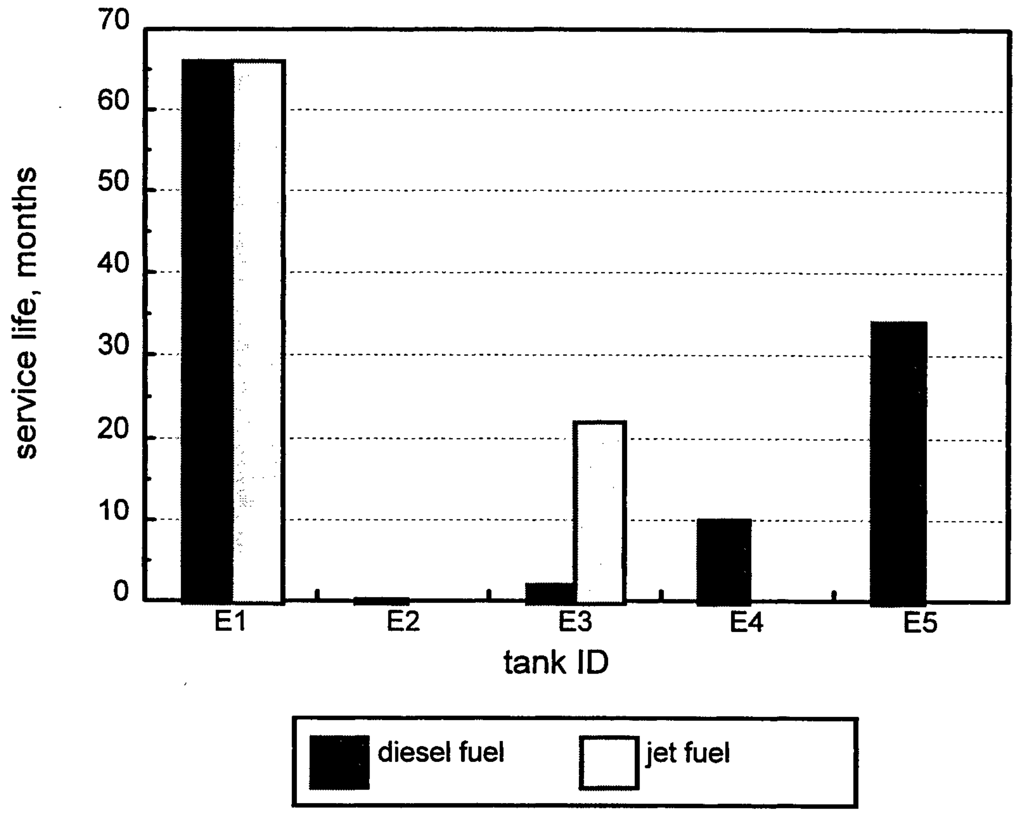
3. Overall, E-5 yielded lower gum contents than E-1.

X. CONCLUSIONS AND RECOMMENDATIONS

The performances of an epichlorohydrin, a nitrile rubber-based, and three polyurethane-type, coated-fabric collapsible fuel tanks were evaluated under subtropical outdoor exposure conditions. Sacrificial pillow tanks made of these five products were filled with a referee grade diesel fuel and a JP-5/JP-8 ST special test turbine fuel. The results obtained from the fuel-filled tanks were compared to those of the empty, fuel-free products. Additionally, 1,900-L (500-gal) capacity minitanks were also made of these products. While all minitanks were tested with diesel fuel, only minitanks made of E-1 and E-3 were also tested with jet fuel.

Measurement results indicate that all examined polyurethane tanks were substantially inferior to those fabricated from the epichlorohydrin or nitrile products, with the latter being superior. Observations on the 1,900-L capacity minitanks are shown on the following barchart to illustrate the expected service lives of these products:

Expected Service Life of Candidate Coated-Fabric Fuel Tanks



It was shown that among the 1,900-L capacity minitanks, the polyurethane-based products could not be pressurized to simulate seam stress values expected in the larger tanks, *e.g.*, those with capacities of 20,000 and 50,000 gal. In the case of two different polyurethane-based tanks, the experiments had to be discontinued within two months of outdoor exposure, while the third polyurethane tank lasted for about 10 months before a catastrophic seam failure occurred when used for storage of diesel fuel. The majority of the problems with the polyurethane tanks were due to poor seam quality, as shown by Photograph 10. It should be noted, however, that grave problems were also found with the structural integrity of the polyurethane tanks, as demonstrated by Photograph 11, in contrast with the performance of the pressurized nitrile tank after 53 months of use, as shown in Photograph 3. The pressurized epichlorohydrin product developed a pinhole on the upper part of the coated fabric

that resulted in continued leakage of fuel after 34 months of exposure. Concurrently, the epichlorohydrin minitank exhibited 1- to 2-mm diameter, fish-scale-type blemishes over the entire surface of the minitank, indicating imminent delamination of the elastomeric coating from the supporting fabric. The nitrile product has been under 60 lb/in. of seam stress for over 66 months, the test limits of this investigation, without adverse incidents.

If products submitted for these experiments by the various manufacturers of coated fabrics are representative of products sold to Department of Defense agencies, then it must be recommended that hydrocarbon fuels not be stored in polyurethane-type products, and that nitrile rubber or epichlorohydrin be the materials of choice for collapsible fuel tanks. It is further recommended that newly developed, candidate fuel tank materials and fabrication techniques be impartially evaluated, *i.e.*, independently from the manufacturers of the coated-fabrics or fabricators of the tanks. Additionally, it is considered most important to examine the effects of the elastomeric coated-fabric fuel tank materials on the quality of the products that they contain, and that if any substantial problems are discovered, actions would be directed to alleviate them.

XI. REFERENCES

1. Memorandum by T.C. Bowen, U.S. Army Belvoir RD&E Center, to S.J. Lestz, TFLRF, dated 03 May 1990, "Draft Project Plan for Outdoor Exposure and Laboratory Studies of Elastomer Seams for Fuel Tanks."

2. Letter by J.O. Hall, U.S. Army Belvoir RD&E Center, to G.E. Fodor, TFLRF, dated 08 August 1990.

3. Fodor, G. E., "Fuel-Elastomer Compatibility Studies - Results of 80 °C/14-Day Experiments," Interim Report BFLRF No. 231, Belvoir Fuels and Lubricants Research Facility at Southwest Research Institute, San Antonio, Texas. Defense Technical Documentation Center accession No. AD A216015, July 1989.

4. Letter by W.F. McGovern, AMSTA-RBWH, to G.E. Fodor, TFLRF, dated 15 March 1995.

5. ASTM D 381, "Standard Test Method for Existent Gum in Fuels by Jet Evaporation."

APPENDIX A
TABLES

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TABLE 1. Physical Test Requirements

Property	Requirement	Test Method	No. of Replicates
Coated fabrics:			
Tear Strength, min. lb	35	ASTM D 2261	5 in each warp and fill directions
Breaking Strength, min. lb/inch	500	FM-191/5102	5 in each warp and fill directions
Diffusion Rate, max. fl oz/ft^2/24 hr	0.15	MIL-T-52983F Par. 4.5.2.12	3 per fuel
Seam sections:			
Breaking Strength, min. lb/inch	500	FM-601/8311	3
Peel Adhesion, min. lb/inch	30	ASTM D 413	3

TABLE 2. Average Results of Preliminary Screening by Physical Testing

Elast. I.D.	DIFFUSION RATE Diesel Fuel	DIFFUSION RATE Turbine Fuel	COATED FABRIC Avg. Breaking Strength Warp	COATED FABRIC Avg. Breaking Strength Fill	COATED FABRIC Avg. Tear Strength Warp	COATED FABRIC Avg. Tear Strength Fill	SEAM SECTION Breaking Strength	SEAM SECTION Peel Adhesion
1	0.012	0.016	879	758	122	93	681	108
2	0.010	0.002	724	764	128	53	687	40
3	0.017	0.003	745	624	103	81	634	28
4	0.026	0.028	743	613	49	38	589	56
5	0.019	0.005	754	567	84	78	763	13
SPECS.:	0.15 fl oz/sq ft/24 hr		500 lbs/inch, minimum		35 lbs, minimum		500 lb/in min	30 lb/in min.

TABLE 3. Analysis of Fuels for Tank Life Extension Program

Property	Method	MIL-F-46162C (Ref. Diesel Fuel) min.	MIL-F-46162C (Ref. Diesel Fuel) max.	MIL-F-46162C (Ref. Diesel Fuel) AL-19525-F	MIL-T-5624N (JP-5/JP-8 ST) min.	MIL-T-5624N (JP-5/JP-8 ST) max.	MIL-T-5624N (JP-5/JP-8 ST) AL-19543-F
Gravity, API at 15°C	D 1298	Report	Report	29.4	42.1	36.0	41.4
Density, kg/L at 15°C	D 1298	Report	Report	0.879	0.815	0.845	0.818
Color	D 1500	NR	NR	2	Report	Report	L 0.5
Flash Point, PPCC, °C	D 93	52	NR	60	60	NR	63
Cloud Point, °C	D 2500	NR	-13	-25	NR	NR	-52
Pour Point, °C	D 97	NR	-18	-41	NR	NR	-52
Freezing Point, °C	D 2386	NR	NR	-20	NR	-46	-49
Smoke Point, mm	D 1322	NR	NR	ND*	18.0	21.0	19.0
K. Viscosity, cSt, at	D 445						
-20°C		NR	NR	ND	NR	8.5	5.5
20°C		NR	NR	ND	NR	NR	ND
40°C		1.9	4.1	3.4	NR	NR	ND
Distillation, °C	D 86						
Initial Boiling Point		Report	Report	152	Report	Report	183
5% Recovered		NR	NR	207	NR	NR	189
10% Recovered		220	NR	228	NR	205	193
20% Recovered		NR	NR	242	Report	Report	195
30% Recovered		NR	NR	254	NR	NR	199
40% Recovered		NR	NR	265	NR	NR	203
50% Recovered		255	305	277	Report	Report	206
60% Recovered		NR	NR	288	NR	NR	211
70% Recovered		NR	NR	299	NR	NR	216
80% Recovered		NR	NR	312	NR	NR	223
90% Recovered		310	360	326	Report	Report	235
95% Recovered		315	365	339	NR	NR	246
End Point		NR	385	351	NR	300	258
Recovered, vol%		Report	Report	98.5	Report	Report	99.0
Residue, vol%		NR	3	1.5	NR	1.5	1.0
Ash, wt%	D 482	NR	0.02	0.01	NR	NR	ND
Carbon Residue, 10% Bottoms, wt%	D 524	NR	0.20	0.14	NR	NR	ND
Filtration Time, min.	D 2276	NR	NR	ND	NR	15	4
Water Reaction Interface	D 1094	NR	NR	ND	NR	1b	1b
Water Separation Index, WISM	D 2550	NR	NR	ND	70	NR	86
Water, ppm	D 1744	NR	NR	277 (a)	NR	NR	93
Particulates, mg/L	D 2276	NR	10.0	4.0	NR	1.0	0.5
Accelerated Stability, mg/dL	D 2274	NR	1.5	0.8	NR	NR	ND
Existent Gum, mg/dL	D 381	NR	NR	ND	NR	7.0	0.2
Thermal Stability, JFTOT	D 3241						
TDR Code		NR	NR	ND	NR	<3	2
max. ΔP, mm Hg		NR	NR	ND	NR	25	0
Neutralization No., mg KOH/g	D 664	NR	0.20	0.01	NR	NR	ND
Total Acid No., mg KOH/g	D 3242	NR	NR	ND	NR	0.015	0.007
Copper Strip Corrosion	D 130	NR	1	1A	NR	1	1A
Electrical Conductivity, pS/m	D 2624	NR	NR	ND	NR	NR	5
Carbon, wt%		NR	NR	ND	NR	NR	86.51
Hydrogen, wt%		NR	NR	ND	13.3	13.5	13.52
Nitrogen, wt%		NR	NR	ND	NR	NR	ND
Sulfur, wt%		0.950	1.050	0.998	NR	0.400	0.020
Mercaptan Sulfur, wt%	D 3227	NR	NR	ND	NR	0.002	0.000
Peroxide No., ppm (wt)	D 3703	NR	NR	ND	NR	8.0	2.0

TABLE 3. Analysis of Fuels for Tank Life Extension Program (cont'd)

Property	Method	MIL-F-46162C (Ref. Diesel Fuel) min.	MIL-F-46162C (Ref. Diesel Fuel) max.	MIL-F-46162C (Ref. Diesel Fuel) AL-19525-F	MIL-T-5624N (JP-5/JP-8 ST) min.	MIL-T-5624N (JP-5/JP-8 ST) max.	MIL-T-5624N (JP-5/JP-8 ST) AL-19543-F
Aromatics, vol%	D 1319	Report	Report	46.0	23.0	27.0	24.5
Olefins, vol%	D 1319	NR	NR	2.4	NR	5.0	1.2
Saturates, vol%	D 1319	NR	NR	51.6	NR	NR	74.3
Aromatic Ring Carbon, wt%	SwRI/UV						
Mononuclear		NR	NR	9.7	NR	NR	10.5
Dinuclear		NR	NR	5.8	NR	NR	4.0
Trinuclear		NR	NR	0.6	NR	NR	0.0
Total		NR	NR	16.1	NR	NR	14.5
Net Heat of Combustion, MJ/kg	D 240	Report	Report	41.4	42.6	NR	ND
Cetane Number	D 613	37.0	43.0	37.0	NR	NR	ND
Cetane Index	D 240	NR	NR	ND	Report	Report	37.6
Additives:							
FOA-15, g/cu.M		71 ± 3	NR	71	NR	NR	ND
Biobor JF, g/cu.M		227 ± 10	NR	227	NR	NR	ND
Cetane Improver, wt%		NR	0.50	ND	NR	NR	ND
Pour Point Depressant		May Use	(b)	(1.0)	NR	NR	ND
Antioxidant, mg/L (lb/Mbbl)		May Use	May Use	ND	NR	24	(7)
Metal Deactivator, mg/gal.		NR	NR	ND	NR	22	ND
Corrosion Inhibitor		May Use	May Use	ND	NR	QPL-25017	(3)
Fuel System Icing Inhibitor, vol%		NR	NR	0.68	NR	MIL-I-85470	0.17
Static Dissipator		NR	NR	ND	NR	ASA-3 or Stadis 450	ND

NOTES:
* ND = Not Determined.
NR - Not Required.
(a) Water conc. without FSII: 227 ppm.
(b) 1.0 vol% EGMME mandatory for this project.

TABLE 4. EVALUATION OF SEAM SECTIONS OF E-1 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E-1, Blank	E-1 with Jet Fuel Measured	E-1 with Jet Fuel % of Blank	E-1 with Diesel Fuel Measured	E-1 with Diesel Fuel % of Blank
05/12/92	6	Breaking Strength	538	364	68	395	73
			628	434	69	409	65
			574	353	61	407	71
		Average	580	384	66	404	70
		St. Dev.	45	44	4	8	4
		Peel Adhesion	75	60	80	67	89
			98	62	63	82	84
			68	63	93	77	113
		Average	80	62	79	75	95
		St. Dev.	16	2	15	8	16
10/28/92	12	Breaking Strength	373	323	87	662	177
12/03/92			419	316	75	637	152
			398	312	78	625	157
			313	361	115	548	175
			306	354	116	545	178
			315	338	107	573	182
		Average	354	334	96	598	170
		St. Dev.	49	20	18	50	12
		Peel Adhesion	74	34	46	67	91
			55	32	58	71	129
			50	42	84	52	104
			76	38	50	57	75
			72	42	58	67	93
			83	47	57	57	69
		Average	68	39	59	62	93
		St. Dev.	13	6	13	7	22
01/12/93	15	Breaking Strength	425	340	80	605	142
			406	356	88	606	149
			353	376	107	563	159
		Average	395	357	91	591	150
		St. Dev.	37	18	14	25	9
		Peel Adhesion	56	42	75	73	130
			64	39	61	68	106
			63	43	68	68	108
		Average	61	41	68	70	115
		St. Dev.	4	2	7	3	13
04/14/93	18	Breaking Strength	428	594	139	555	130
			135	619	459	502	372
			409	566	138	570	139
		Average	324	593	245	542	214
		St. Dev.	164	27	185	36	137
		Peel Adhesion	50	29	58	53	106
			46	29	63	55	120
			55	43	78	49	89
		Average	50	34	66	52	105
		St. Dev.	5	8	11	3	15

TABLE 4. EVALUATION OF SEAM SECTIONS OF E-1 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E1B6	E-1 with Jet Fuel Measured	E-1 with Jet Fuel % of Blank	E-1 with Diesel Fuel Measured	E-1 with Diesel Fuel % of Blank
10/11/93	24	Breaking Strength	408	330	81	555	136
			438	391	89	522	119
			434	355	82	508	117
		Average	427	359	84	528	124
		St. Dev.	16	31	5	24	10
		Peel Adhesion	57	49	86	47	82
			64	39	61	54	84
			64	47	73	46	72
		Average	62	45	73	49	80
		St. Dev.	4	5	13	4	7
04/21/94	30	Breaking Strength	406	558	137	510	126
			444	515	116	584	132
			450	492	109	493	110
		Average	433	522	121	529	122
		St. Dev.	24	34	15	48	11
		Peel Adhesion	54	40	74	53	98
			53	33	62	53	100
			53	37	70	56	106
		Average	53	37	69	54	101
		St. Dev.	1	4	6	2	4
10/17/94	36	Breaking Strength	436	374	86	497	114
			395	380	96	445	113
			493	366	74	518	105
		Average	441	373	85	487	111
		St. Dev.	49	7	11	38	5
		Peel Adhesion	38	24	63	49	129
			41	13	32	43	105
			50	19	38	42	84
		Average	43	19	44	45	106
		St. Dev.	6	6	17	4	22
04/17/95	42	Breaking Strength	492	443	90	580	118
			461	445	97	655	142
			468	478	102	621	133
		Average	474	455	96	619	131
		St. Dev.	16	20	6	38	12
		Peel Adhesion	51	42	82	3	6
			62	37	60	51	82
			55	40	73	48	87
		Average	56	40	72	34	58
		St. Dev.	6	3	11	27	46
10/14/95	48	Breaking Strength	471	480	102	477	101
			462	465	101	504	109
			454	472	104	508	112
		Average	462	472	102	496	107
		St. Dev.	9	8	2	17	6
		Peel Adhesion	51	38	75	31	61
			52	33	63	36	69
			54	38	70	49	91
		Average	52	36	69	39	74
		St. Dev.	2	3	6	9	15

TABLE 4. EVALUATION OF SEAM SECTIONS OF E-1 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E1B6	E-1 with Jet Fuel Measured	E-1 with Jet Fuel % of Blank	E-1 with Diesel Fuel Measured	E-1 with Diesel Fuel % of Blank
04/16/96	54	Breaking Strength	575	452	79	520	662
			575	472	82	570	694
			502	455	91	536	591
		Average	551	460	84	542	649
		St. Dev.	42	11	6	26	53
		Peel Adhesion	43	41	95	44	46
			49	40	82	44	54
			47	40	85	43	51
		Average	46	40	87	44	50
		St. Dev.	3	1	7	1	4
11/14/96	60	Breaking Strength	456	551	121	506	419
			401	569	142	490	345
			452	536	119	555	468
		Average	436	552	127	517	411
		St. Dev.	31	17	13	34	62
		Peel Adhesion	48	41	85	43	50
			44	42	95	50	52
			50	37	74	50	68
		Average	47	40	85	48	57
		St. Dev.	3	3	11	4	9
04/17/97	66	Breaking Strength	444	509	115	424	95
			456	515	113	440	96
			476	488	103	449	94
		Average	459	504	110	438	95
		St. Dev.	16	14	7	13	1
		Peel Adhesion	54	66	122	51	94
			59	22	37	44	75
			56	34	61	56	100
		Average	56	41	73	50	90
		St. Dev.	3	23	44	6	13

c:\..\outdoor\seamdata.wb3

TABLE 5. EVALUATION OF SEAM SECTIONS OF E-2 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E-2, Blank	E-2 with Jet Fuel		E-2 with Diesel Fuel	
				Measured	% of Blank	Measured	% of Blank
01/12/93	3	Breaking Strength	821	709	86	711	87
			775	740	95	734	95
			802	688	86	714	89
		Average	799	712	89	720	90
		St. Dev.	23	26	5	13	4
		Peel Adhesion	34	51	150	43	126
			42	56	133	39	93
			35	56	160	38	109
		Average	37	54	148	40	109
		St. Dev.	4	3	13	3	17
04/14/93	6	Breaking Strength	682	688	101	732	107
			643	676	105	772	120
			672	723	108	734	109
		Average	666	696	105	746	112
		St. Dev.	20	24	3	23	7
		Peel Adhesion	30	58	193	53	177
			28	61	218	54	193
			27	54	200	63	233
		Average	28	58	204	57	201
		St. Dev.	2	4	13	6	29
10/11/93	12	Breaking Strength	695	730	105	339	49
			708	700	99	335	47
			744	751	101	403	54
		Average	716	727	102	359	50
		St. Dev.	25	26	3	38	4
		Peel Adhesion	22	17	77	7	32
			39	14	36	21	54
			23	13	57	9	39
		Average	28	15	57	12	42
		St. Dev.	10	2	21	8	11
04/21/94	18	Breaking Strength	683	584	86	471	69
			700	608	87	451	64
			780	588	75	370	47
		Average	721	593	83	431	60
		St. Dev.	52	13	6	53	11
		Peel Adhesion	31	12	39	3	10
			53	11	21	4	8
			30	15	50	4	13
		Average	38	13	36	4	10
		St. Dev.	13	2	15	1	3
10/17/94	24	Breaking Strength	746	415	56	438	59
			848	285	34	324	38
			831	248	30	376	45
		Average	808	316	40	379	47
		St. Dev.	55	88	14	57	10
		Peel Adhesion	24	2	8	4	17
			26	2	8	3	12
			47	6	13	3	6
		Average	32	3	10	3	12
		St. Dev.	13	2	3	1	5

TABLE 5. EVALUATION OF SEAM SECTIONS OF E-2 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property		E-2, Blank	E-2, with Jet Fuel		E-2 with Diesel Fuel	
					Measured	% of Blank	Measured	% of Blank
04/17/95	30	Breaking Strength		751	343	46	-----	-----
				715	353	49	-----	-----
				754	296	39	-----	-----
			Average	740	331	45	-----	-----
			St. Dev.	22	30	5	-----	-----
		Peel Adhesion		12	9	75	-----	-----
				12	3	25	-----	-----
				35	2	6	-----	-----
			Average	20	5	35	-----	-----
			St. Dev.	13	4	36	-----	-----
10/14/95	36	Breaking Strength		783	261	33	-----	-----
				811	218	27	-----	-----
				746	241	32	-----	-----
			Average	780	240	31	-----	-----
			St. Dev.	33	22	3	-----	-----
		Peel Adhesion		49	1	2	-----	-----
				46	1	2	-----	-----
				41	1	2	-----	-----
			Average	45	1	2	-----	-----
			St. Dev.	4	0	0	-----	-----
04/16/96	42	Breaking Strength		759	234	31	-----	-----
				726	291	40	-----	-----
				769	228	30	-----	-----
			Average	751	251	34	-----	-----
			St. Dev.	23	35	6	-----	-----
		Peel Adhesion		35	2	6	-----	-----
				26	5	19	-----	-----
				39	5	13	-----	-----
			Average	33	4	13	-----	-----
			St. Dev.	7	2	7	-----	-----
11/14/96	48	Breaking Strength		597	-----	-----	-----	-----
				715	-----	-----	-----	-----
				745	-----	-----	-----	-----
			Average	686	-----	-----	-----	-----
			St. Dev.	78	-----	-----	-----	-----
		Peel Adhesion		17	-----	-----	-----	-----
				27	-----	-----	-----	-----
				15	-----	-----	-----	-----
			Average	20	-----	-----	-----	-----
			St. Dev.	6	-----	-----	-----	-----
04/17/97	54	Breaking Strength		802	-----	-----	-----	-----
				765	-----	-----	-----	-----
				722	-----	-----	-----	-----
			Average	763	-----	-----	-----	-----
			St. Dev.	40	-----	-----	-----	-----
		Peel Adhesion		32	-----	-----	-----	-----
				28	-----	-----	-----	-----
				49	-----	-----	-----	-----
			Average	36	-----	-----	-----	-----
			St. Dev.	11	-----	-----	-----	-----

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TABLE 6. EVALUATION OF SEAM SECTIONS OF E-3 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E-3, Blank	E-3 with Jet Fuel Measured	E-3 with Jet Fuel % of Blank	E-3 with Diesel Fuel Measured	E-3 with Diesel Fuel % of Blank
01/12/93	3	Breaking Strength	564	571	101	584	104
			564	569	101	539	96
			542	556	103	519	96
		Average	557	565	102	547	98
		St. Dev.	13	8	1	33	5
		Peel Adhesion	56	58	104	78	139
			49	63	129	76	155
			49	48	98	76	155
		Average	51	56	110	77	150
		St. Dev.	4	8	16	1	9
04/14/93	6	Breaking Strength	540	540	100	531	98
			578	487	84	479	83
			552	559	101	517	94
		Average	557	529	95	509	92
		St. Dev.	19	37	9	27	8
		Peel Adhesion	43	56	130	65	151
			53	67	126	39	74
			49	61	124	84	171
		Average	48	61	127	63	132
		St. Dev.	5	6	3	23	52
10/11/93	12	Breaking Strength	561	480	86	449	80
			559	491	88	262	47
			559	364	65	217	39
		Average	560	445	80	309	55
		St. Dev.	1	70	13	123	22
		Peel Adhesion	59	25	42	19	32
			50	31	62	19	38
			55	33	60	14	25
		Average	55	30	55	17	32
		St. Dev.	5	4	11	3	6
04/21/94	18	Breaking Strength	456	431	95	282	62
			410	393	96	110	27
			451	410	91	101	22
		Average	439	411	94	164	37
		St. Dev.	25	19	3	102	22
		Peel Adhesion	55	39	71	5	9
			57	28	49	5	9
			65	33	51	4	6
		Average	59	33	57	5	8
		St. Dev.	5	6	12	1	2
10/17/94	24	Breaking Strength	474	50	11	25	5
			472	58	12	21	4
			433	61	14	14	3
		Average	460	56	12	20	4
		St. Dev.	23	6	2	6	1
		Peel Adhesion	34	1	3	-----	-----
			45	1	2	-----	-----
			54	3	6	-----	-----
		Average	44	2	4	-----	-----
		St. Dev.	10	1	2	-----	-----

TABLE 6. EVALUATION OF SEAM SECTIONS OF E-3 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property		E-3, Blank	E-3 with Jet Fuel		E-3 with Diesel Fuel	
					Measured	% of Blank	Measured	% of Blank
04/17/95	30	Breaking Strength		486	104	21	-----	-----
				463	73	16	-----	-----
				489	61	12	-----	-----
			Average	479	79	17	-----	-----
			St. Dev.	14	22	5	-----	-----
		Peel Adhesion		29	0	0	-----	-----
				44	1	2	-----	-----
				33	1	3	-----	-----
			Average	35	1	2	-----	-----
			St. Dev.	8	1	2	-----	-----
10/14/95	36	Breaking Strength		458	20	4	-----	-----
				413	17	4	-----	-----
				361	21	6	-----	-----
			Average	411	19	5	-----	-----
			St. Dev.	49	2	1	-----	-----
		Peel Adhesion		16	-----	-----	-----	-----
				26	-----	-----	-----	-----
				28	-----	-----	-----	-----
			Average	23	-----	-----	-----	-----
			St. Dev.	6	-----	-----	-----	-----
04/16/96	42	Breaking Strength		459	-----	-----	-----	-----
				474	-----	-----	-----	-----
				489	-----	-----	-----	-----
			Average	474	-----	-----	-----	-----
			St. Dev.	15	-----	-----	-----	-----
		Peel Adhesion		17	-----	-----	-----	-----
				28	-----	-----	-----	-----
				23	-----	-----	-----	-----
			Average	23	-----	-----	-----	-----
			St. Dev.	6	-----	-----	-----	-----
11/14/96	48	Breaking Strength		436	-----	-----	-----	-----
				439	-----	-----	-----	-----
				414	-----	-----	-----	-----
			Average	430	-----	-----	-----	-----
			St. Dev.	14	-----	-----	-----	-----
		Peel Adhesion		14	-----	-----	-----	-----
				15	-----	-----	-----	-----
				16	-----	-----	-----	-----
			Average	15	-----	-----	-----	-----
			St. Dev.	1	-----	-----	-----	-----
04/17/97	54	Breaking Strength		436	-----	-----	-----	-----
				398	-----	-----	-----	-----
				394	-----	-----	-----	-----
			Average	409	-----	-----	-----	-----
			St. Dev.	23	-----	-----	-----	-----
		Peel Adhesion		27	-----	-----	-----	-----
				18	-----	-----	-----	-----
				15	-----	-----	-----	-----
			Average	20	-----	-----	-----	-----
			St. Dev.	6	-----	-----	-----	-----

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TABLE 7. EVALUATION OF SEAM SECTIONS OF E-4 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E-4, Blank	E-4 with Jet Fuel Measured	E-4 with Jet Fuel % of Blank	E-4 with Diesel Fuel Measured	E-4 with Diesel Fuel % of Blank
01/12/93	3	Breaking Strength	504	547	109	571	113
			470	533	113	546	116
			498	504	101	529	106
		Average	491	528	108	549	112
		St. Dev.	18	22	6	21	5
		Peel Adhesion	76	62	82	33	43
			54	62	115	40	74
			70	50	71	27	39
		Average	67	58	89	33	52
		St. Dev.	11	7	23	7	19
04/14/93	6	Breaking Strength	499	381	76	625	125
			534	424	79	563	105
			677	467	69	581	86
		Average	570	424	75	590	106
		St. Dev.	94	43	5	32	20
		Peel Adhesion	42	80	190	24	57
			45	55	122	22	49
			25	76	304	28	112
		Average	37	70	206	25	73
		St. Dev.	11	13	92	3	34
10/11/93	12	Breaking Strength	566	447	79	353	62
			525	502	96	265	50
			594	494	83	232	39
		Average	562	481	86	283	51
		St. Dev.	35	30	9	63	12
		Peel Adhesion	78	50	64	8	10
			79	59	75	13	16
			81	47	58	9	11
		Average	79	52	66	10	13
		St. Dev.	2	6	8	3	3
04/21/94	18	Breaking Strength	606	522	86	74	12
			626	494	79	36	6
			641	521	81	30	5
		Average	624	512	82	47	8
		St. Dev.	18	16	4	24	4
		Peel Adhesion	58	86	148	1	2
			64	73	114	5	8
			87	88	101	4	5
		Average	70	82	121	3	5
		St. Dev.	15	8	24	2	3
10/17/94	24	Breaking Strength	579	421	73	24	4
			599	417	70	9	2
			598	476	80	3	1
		Average	592	438	74	12	2
		St. Dev.	11	33	5	11	2
		Peel Adhesion	73	11	15	-----	-----
			87	15	17	-----	-----
			84	20	24	-----	-----
		Average	81	15	19	-----	-----
		St. Dev.	7	5	5	-----	-----

TABLE 7. EVALUATION OF SEAM SECTIONS OF E-4 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property		E4B6	E4J6		E4D6	
					Measured	% of Blank	Measured	% of Blank
04/17/95	30	Breaking Strength		621	289	47	-----	-----
				625	109	17	-----	-----
				679	98	14	-----	-----
			Average	642	165	26	-----	-----
			St. Dev.	32	107	18	-----	-----
		Peel Adhesion		64	12	19	-----	-----
				85	3	4	-----	-----
				66	2	3	-----	-----
			Average	72	6	8	-----	-----
			St. Dev.	12	6	9	-----	-----
10/14/95	36	Breaking Strength		626	-----	-----	-----	-----
				577	-----	-----	-----	-----
				592	-----	-----	-----	-----
			Average	598	-----	-----	-----	-----
			St. Dev.	25	-----	-----	-----	-----
		Peel Adhesion		21	-----	-----	-----	-----
				34	-----	-----	-----	-----
				21	-----	-----	-----	-----
			Average	25	-----	-----	-----	-----
			St. Dev.	8	-----	-----	-----	-----
04/16/96	42	Breaking Strength		627	-----	-----	-----	-----
				668	-----	-----	-----	-----
				573	-----	-----	-----	-----
			Average	623	-----	-----	-----	-----
			St. Dev.	48	-----	-----	-----	-----
		Peel Adhesion		40	-----	-----	-----	-----
				70	-----	-----	-----	-----
				97	-----	-----	-----	-----
			Average	69	-----	-----	-----	-----
			St. Dev.	29	-----	-----	-----	-----
11/14/96	48	Breaking Strength		568	-----	-----	-----	-----
				466	-----	-----	-----	-----
				703	-----	-----	-----	-----
			Average	579	-----	-----	-----	-----
			St. Dev.	119	-----	-----	-----	-----
		Peel Adhesion		28	-----	-----	-----	-----
				27	-----	-----	-----	-----
				7	-----	-----	-----	-----
			Average	21	-----	-----	-----	-----
			St. Dev.	12	-----	-----	-----	-----
04/17/97	54	Breaking Strength		499	-----	-----	-----	-----
				417	-----	-----	-----	-----
				370	-----	-----	-----	-----
			Average	429	-----	-----	-----	-----
			St. Dev.	65	-----	-----	-----	-----
		Peel Adhesion		20	-----	-----	-----	-----
				5	-----	-----	-----	-----
				9	-----	-----	-----	-----
			Average	11	-----	-----	-----	-----
			St. Dev.	8	-----	-----	-----	-----

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TABLE 8. EVALUATION OF SEAM SECTIONS OF E-5 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property		E-5, Blank	E-5, with Jet Fuel		E-5 with Diesel Fuel	
					Measured	% of Blank	Measured	% of Blank
01/12/93	3	Breaking Strength		516	510	99	577	112
				566	506	89	556	98
				540	496	92	580	107
			Average	541	504	93	571	106
			St. Dev.	25	7	5	13	7
		Peel Adhesion		18	23	128	48	267
				36	24	67	47	131
				34	23	68	41	121
			Average	29	23	87	45	173
			St. Dev.	10	1	35	4	82
04/14/93	6	Breaking Strength		493	468	95	618	125
				477	425	89	613	129
				477	496	104	570	119
			Average	482	463	96	600	124
			St. Dev.	9	36	8	26	5
		Peel Adhesion		24	34	142	25	104
				17	30	176	29	171
				13	51	392	22	169
			Average	18	38	237	25	148
			St. Dev.	6	11	136	4	38
10/11/93	12	Breaking Strength		546	458	84	555	102
				537	435	81	506	94
				573	455	79	556	97
			Average	552	449	81	539	98
			St. Dev.	19	13	2	29	4
		Peel Adhesion		26	24	92	28	108
				30	20	67	26	87
				28	26	93	25	89
			Average	28	23	84	26	95
			St. Dev.	2	3	15	2	11
04/21/94	18	Breaking Strength		648	607	94	468	72
				659	591	90	613	93
				570	598	105	591	104
			Average	626	599	96	557	90
			St. Dev.	49	8	8	78	16
		Peel Adhesion		29	11	38	32	110
				28	12	43	31	111
				25	11	44	30	120
			Average	27	11	42	31	114
			St. Dev.	2	1	3	1	5
10/17/94	24	Breaking Strength		352	505	143	540	153
				499	490	98	594	119
				302	499	165	565	187
			Average	384	498	136	566	153
			St. Dev.	102	8	34	27	34
		Peel Adhesion		22	10	45	22	100
				20	13	65	22	110
				23	10	43	20	87
			Average	22	11	51	21	99
			St. Dev.	2	2	12	1	12

TABLE 8. EVALUATION OF SEAM SECTIONS OF E-5 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E-5, Blank	E-5, with Jet Fuel		E-5 with Diesel Fuel	
				Measured	% of Blank	Measured	% of Blank
04/17/95	30	Breaking Strength	526	637	121	480	91
			548	565	103	597	109
			501	680	136	624	125
		Average	525	627	120	567	108
		St. Dev.	24	58	16	77	17
		Peel Adhesion	21	14	67	24	114
			21	28	133	36	171
			20	19	95	21	105
		Average	21	20	98	27	130
		St. Dev.	1	7	33	8	36
10/14/95	36	Breaking Strength	584	501	86	477	82
			607	535	88	504	83
			694	496	71	508	73
		Average	628	511	82	496	79
		St. Dev.	58	21	9	17	5
		Peel Adhesion	27	12	44	17	63
			27	8	30	17	63
			27	21	78	14	52
		Average	27	14	51	16	59
		St. Dev.	0	7	25	2	6
04/16/96	42	Breaking Strength	526	591	112	394	75
			596	615	103	330	55
			521	631	121	403	77
		Average	548	612	112	376	69
		St. Dev.	42	20	9	40	12
		Peel Adhesion	24	20	83	10	42
			12	17	142	16	133
			11	16	145	14	127
		Average	16	18	123	13	101
		St. Dev.	7	2	35	3	51
11/14/96	48	Breaking Strength	647	612	95	530	82
			613	690	113	580	95
			644	674	105	510	79
		Average	635	659	104	540	85
		St. Dev.	19	41	9	36	8
		Peel Adhesion	24	16	67	22	92
			24	17	71	28	117
			22	8	36	26	118
		Average	23	14	58	25	109
		St. Dev.	1	5	19	3	15
04/17/97	54	Breaking Strength	640	545	85	615	96
			592	524	89	649	110
			607	582	96	658	108
		Average	613	550	90	641	105
		St. Dev.	25	29	5	23	7
		Peel Adhesion	26	14	54	24	92
			27	21	78	25	93
			24	14	58	23	96
		Average	26	16	63	24	94
		St. Dev.	2	4	13	1	2

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TABLE 9. SUMMARY OF EFFECTS OF OUTDOOR EXPOSURE ON SEAMS OF COATED-FABRIC TANKS
EFFECT OF COMPOSITION

		Control (Blank) Sample				Jet Fuel				Diesel Fuel			
		Breaking Strength		Peel Adhesion		Breaking Strength		Peel Adhesion		Breaking Strength		Peel Adhesion	
Elastomer I.D.	Exposure Months	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.
E-1	6	580	45	80	16	384	44	62	2	404	8	75	8
E-2	6	666	20	28	2	696	24	58	4	746	23	57	6
E-3	6	557	19	48	5	529	37	61	6	509	27	63	23
E-4	6	570	94	37	11	424	43	70	13	590	32	25	3
E-5	6	482	9	18	6	463	36	38	11	600	26	25	4
E-1	12	354	49	68	13	334	20	39	6	598	50	62	7
E-2	12	716	25	28	10	727	26	15	2	359	38	12	8
E-3	12	560	1	55	5	445	70	30	4	309	123	17	3
E-4	12	562	35	79	2	481	30	52	6	283	63	10	3
E-5	12	552	19	28	2	449	13	23	3	539	29	26	2
E-1	18	324	164	50	5	593	27	34	8	542	36	52	3
E-2	18	721	52	38	13	593	13	13	2	431	53	4	1
E-3	18	439	25	59	5	411	19	33	6	164	102	5	1
E-4	18	624	18	70	15	512	16	82	8	47	24	3	2
E-5	18	626	49	27	2	599	8	11	1	557	78	31	1
E-1	24	427	16	62	4	359	31	45	5	528	24	49	4
E-2	24	808	55	32	13	316	88	3	2	379	57	3	1
E-3	24	460	23	44	10	56	6	2	1	20	6	----	----
E-4	24	592	11	81	7	438	33	15	5	12	11	----	----
E-5	24	384	102	22	2	498	8	11	2	566	27	21	1
E-1	30	433	24	53	1	522	34	37	4	529	48	54	2
E-2	30	740	22	20	13	321	29	5	4	----	----	----	----
E-3	30	479	14	35	8	79	22	1	1	----	----	----	----
E-4	30	642	32	72	12	165	107	6	6	----	----	----	----
E-5	30	525	24	21	1	627	58	20	7	567	77	27	8
E-1	36	441	49	43	6	373	7	19	6	487	38	45	4
E-2	36	780	33	45	4	240	22	1	----	----	----	----	----
E-3	36	411	49	23	6	----	----	----	----	----	----	----	----
E-4	36	598	25	25	8	----	----	----	----	----	----	----	----
E-5	36	628	58	27	0	511	21	14	7	496	17	16	2
E-1	42	474	16	56	6	455	20	40	3	619	38	34	27
E-2	42	751	23	33	7	251	35	4	2	----	----	----	----
E-3	42	474	15	23	6	----	----	----	----	----	----	----	----
E-4	42	623	48	69	29	----	----	----	----	----	----	----	----
E-5	42	548	42	16	7	612	20	18	2	376	40	13	3
E-1	48	462	9	52	2	472	8	36	3	496	17	39	9
E-2	48	686	78	20	6	----	----	----	----	----	----	----	----
E-3	48	430	14	15	1	----	----	----	----	----	----	----	----
E-4	48	517	119	28	12	----	----	----	----	----	----	----	----
E-5	48	635	19	23	1	659	41	14	5	540	36	25	3
E-1	54	551	42	46	3	460	11	40	1	542	26	44	1
E-2	54	763	40	36	11	----	----	----	----	----	----	----	----
E-3	54	409	23	20	6	----	----	----	----	----	----	----	----
E-4	54	429	65	11	8	----	----	----	----	----	----	----	----
E-5	54	613	25	26	2	550	29	16	4	641	23	24	1
E-1	60	436	31	47	3	552	17	40	3	517	34	48	4
E-1	66	459	16	56	3	504	14	41	23	438	13	50	6

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TABLE 10. SUMMARY OF EFFECTS OF OUTDOOR EXPOSURE ON SEAMS OF COATED-FABRIC TANKS EFFECT OF TIME

		Control (Blank) Sample				Jet Fuel				Diesel Fuel			
		Breaking Strength		Peel Adhesion		Breaking Strength		Peel Adhesion		Breaking Strength		Peel Adhesion	
Elastomer I.D.	Exposure Months	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.
E-1	6	580	45	80	16	384	44	62	2	404	8	75	8
E-1	12	354	49	68	13	334	20	39	6	598	50	62	7
E-1	18	324	164	50	5	593	27	34	8	542	36	52	3
E-1	24	427	16	62	4	359	31	45	5	528	24	49	4
E-1	30	433	24	53	1	522	34	37	4	529	48	54	2
E-1	36	441	49	43	6	373	7	19	6	487	38	45	4
E-1	42	474	16	56	6	455	20	40	3	619	38	34	27
E-1	48	462	9	52	2	472	8	36	3	496	17	39	9
E-1	54	551	42	46	3	460	11	40	1	542	26	44	1
E-1	60	436	31	47	3	552	17	40	3	517	34	48	4
E-1	66	459	16	56	3	504	14	41	23	438	13	50	6
E-2	6	666	20	28	2	696	24	58	4	746	23	57	6
E-2	12	716	25	28	10	727	26	15	2	359	38	12	8
E-2	18	721	52	38	13	593	13	13	2	431	53	4	1
E-2	24	808	55	32	13	316	88	3	2	379	57	3	1
E-2	30	740	22	20	13	321	29	5	4	----	----	----	----
E-2	36	780	33	45	4	240	22	1	0	----	----	----	----
E-2	42	751	23	33	7	251	35	4	2	----	----	----	----
E-2	48	686	78	20	6	----	----	----	----	----	----	----	----
E-2	54	763	40	36	11	----	----	----	----	----	----	----	----
E-3	6	557	19	48	5	529	37	61	6	509	27	63	23
E-3	12	560	1	55	5	445	70	30	4	309	123	17	3
E-3	18	439	25	59	5	411	19	33	6	164	102	5	1
E-3	24	460	23	44	10	56	6	2	1	20	6	----	----
E-3	30	479	14	35	8	79	22	1	1	----	----	----	----
E-3	36	411	49	23	6	19	2	----	----	----	----	----	----
E-3	42	474	15	23	6	----	----	----	----	----	----	----	----
E-3	48	430	14	15	1	----	----	----	----	----	----	----	----
E-3	54	409	23	20	6	----	----	----	----	----	----	----	----
E-4	6	570	94	37	11	424	43	70	13	590	32	25	3
E-4	12	562	35	79	2	481	30	52	6	283	63	10	3
E-4	18	624	18	70	15	512	16	82	8	47	24	3	2
E-4	24	592	11	81	7	438	33	15	5	12	11	----	----
E-4	30	642	32	72	12	165	107	6	6	----	----	----	----
E-4	36	598	25	25	8	----	----	----	----	----	----	----	----
E-4	42	623	48	69	29	----	----	----	----	----	----	----	----
E-4	48	517	119	28	12	----	----	----	----	----	----	----	----
E-4	54	429	65	11	8	----	----	----	----	----	----	----	----
E-5	6	482	9	18	6	463	36	38	11	600	26	25	4
E-5	12	552	19	28	2	449	13	23	3	539	29	26	2
E-5	18	626	49	27	2	599	8	11	1	557	78	31	1
E-5	24	384	102	22	2	498	8	11	2	566	27	21	1
E-5	30	525	24	21	1	627	58	20	7	567	77	27	8
E-5	36	628	58	27	0	511	21	14	7	496	17	16	2
E-5	42	548	42	16	7	612	20	18	2	376	40	13	3
E-5	48	635	19	23	1	659	41	14	5	540	36	25	3
E-5	54	613	25	26	2	550	29	16	4	641	23	24	1

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Table 11. Breaking Strength of Coated Fabric Sections

Elastomer ID.	Exposure months	Blank fill	Blank warp	Jet fuel fill	Jet fuel warp	Diesel fuel fill	Diesel fuel warp
E-1 pre. data *	0	758	879	-----	-----	-----	-----
E-1	42	365	722	398	640	588	712
E-1	42	346	685	430	686	612	742
E-1	42	364	760	420	717	623	709
average:	42	358	722	416	681	608	721
smpl. std. dev.:	42	9	31	13	32	15	15
E-1	48	628	395	658	385	680	398
E-1	48	709	331	679	318	671	412
E-1	48	686	336	664	349	741	429
average	48	674	354	667	351	697	413
smpl. std. dev.:	48	34	29	9	27	31	13
E-1	54	710	303	646	353	768	492
E-1	54	717	333	696	337	752	533
E-1	54	674	309	671	328	757	544
average	54	700	315	671	339	759	523
smpl. std. dev.:	54	23	16	25	13	8	27
E-1	60	664	371	743	552	773	580
E-1	60	706	313	700	599	740	614
E-1	60	732	336	738	560	727	591
average	60	701	340	727	570	747	595
smpl. std. dev.:	60	34	29	24	25	24	17
E-1	66	742	387	601	532	679	427
E-1	66	734	370	621	565	673	410
E-1	66	705	399	628	590	597	357
average	66	727	385	617	562	650	398
smpl. std. dev.:	66	19	15	14	29	46	37
E-2 pre. data *	0	764	724	-----	-----	-----	-----
E-2	30	781	796	550	21	-----	-----
E-2	30	829	805	540	403	-----	-----
E-2	30	786	792	561	411	-----	-----
average:	30	799	798	550	278	-----	-----
smpl. std. dev.:	30	22	5	9	182	-----	-----
E-2	36	806	687	293	417	-----	-----
E-2	36	791	700	327	391	-----	-----
E-2	36	786	681	304	417	-----	-----
average:	36	794	689	308	408	-----	-----
smpl. std. dev.:	36	8	8	14	12	-----	-----
E-2	42	841	783	373	492	-----	-----
E-2	42	852	749	351	497	-----	-----
E-2	42	857	747	361	521	-----	-----
average	42	850	760	362	503	-----	-----
smpl. std. dev.:	42	8	20	11	16	-----	-----
E-2	48	847	687	-----	-----	-----	-----
E-2	48	849	735	-----	-----	-----	-----
E-2	48	802	695	-----	-----	-----	-----
average	48	833	706	-----	-----	-----	-----
smpl. std. dev.:	48	27	26	-----	-----	-----	-----
E-2	54	814	734	-----	-----	-----	-----
E-2	54	811	727	-----	-----	-----	-----
E-2	54	828	703	-----	-----	-----	-----
average	54	818	721	-----	-----	-----	-----
smpl. std. dev.:	54	9	16	-----	-----	-----	-----

Table 11. Breaking Strength of Coated Fabric Sections (continued)

Elastomer ID.	Exposure months	Blank fill	Blank warp	Jet fuel fill	Jet fuel warp	Diesel fuel fill	Diesel fuel warp
E-3 pre. data *	0	624	745	-----	-----	-----	-----
E-3	30	512	736	318	435	-----	-----
E-3	30	504	720	330	434	-----	-----
E-3	30	520	733	303	316	-----	-----
average:	30	512	730	317	395	-----	-----
smpl. std. dev.:	30	7	7	11	56	-----	-----
E-3	36	643	412	377	243	-----	-----
E-3	36	624	404	408	230	-----	-----
E-3	36	615	359	316	237	-----	-----
average:	36	627	392	367	237	-----	-----
smpl. std. dev.:	36	12	23	38	5	-----	-----
E-3	42	660	446	-----	-----	-----	-----
E-3	42	617	451	-----	-----	-----	-----
E-3	42	677	430	-----	-----	-----	-----
average:	42	651	442	-----	-----	-----	-----
smpl. std. dev.:	42	31	11	-----	-----	-----	-----
E-3	48	738	377	-----	-----	-----	-----
E-3	48	683	384	-----	-----	-----	-----
E-3	48	647	382	-----	-----	-----	-----
average:	48	689	381	-----	-----	-----	-----
smpl. std. dev.:	48	46	4	-----	-----	-----	-----
E-3	54	686	391	-----	-----	-----	-----
E-3	54	704	339	-----	-----	-----	-----
E-3	54	732	410	-----	-----	-----	-----
average:	54	707	380	-----	-----	-----	-----
smpl. std. dev.:	54	23	37	-----	-----	-----	-----
E-4 pre. data *	0	613	743	-----	-----	-----	-----
E-4	30	571	761	278	543	-----	-----
E-4	30	559	759	299	510	-----	-----
E-4	30	567	754	310	497	-----	-----
average:	30	566	758	296	517	-----	-----
smpl. std. dev.:	30	5	3	13	19	-----	-----
E-4	36	771	591	-----	-----	-----	-----
E-4	36	749	618	-----	-----	-----	-----
E-4	36	735	626	-----	-----	-----	-----
average:	36	752	612	-----	-----	-----	-----
smpl. std. dev.:	36	15	15	-----	-----	-----	-----
E-4	42	787	634	-----	-----	-----	-----
E-4	42	770	588	-----	-----	-----	-----
E-4	42	729	625	-----	-----	-----	-----
average:	42	762	616	-----	-----	-----	-----
smpl. std. dev.:	42	30	24	-----	-----	-----	-----
E-4	48	580	736	-----	-----	-----	-----
E-4	48	576	749	-----	-----	-----	-----
E-4	48	577	718	-----	-----	-----	-----
average:	48	578	734	-----	-----	-----	-----
smpl. std. dev.:	48	2	16	-----	-----	-----	-----
E-4	54	732	478	-----	-----	-----	-----
E-4	54	754	495	-----	-----	-----	-----
E-4	54	755	537	-----	-----	-----	-----
average:	54	747	503	-----	-----	-----	-----
smpl. std. dev.:	54	13	30	-----	-----	-----	-----

Table 11. Breaking Strength of Coated Fabric Sections (continued)

Elastomer ID.	Exposure months	Blank fill	Blank warp	Jet fuel fill	Jet fuel warp	Diesel fuel fill	Diesel fuel warp
E-5 pre. data *	0	567	754	-----	-----	-----	-----
E-5	30	388	729	626	682	597	724
E-5	30	532	703	713	634	553	726
E-5	30	490	737	706	632	525	747
average:	30	470	723	682	649	558	732
smpl. std. dev.:	30	60	15	39	23	30	10
E-5	36	555	627	688	593	751	693
E-5	36	549	561	646	615	740	704
E-5	36	613	582	706	583	781	683
average:	36	572	590	680	597	757	693
smpl. std. dev.:	36	29	28	25	13	17	9
E-5	42	764	570	722	639	751	546
E-5	42	773	580	670	644	720	501
E-5	42	786	516	627	650	746	493
average:	42	774	555	673	644	739	513
smpl. std. dev.:	42	11	34	48	6	17	29
E-5	48	730	581	526	602	789	681
E-5	48	767	575	515	615	783	672
E-5	48	772	601	540	598	777	692
average:	48	756	586	527	605	783	682
smpl. std. dev.:	48	23	14	13	9	6	10
E-5	54	713	617	775	575	742	598
E-5	54	719	619	745	608	772	637
E-5	54	770	624	755	587	742	633
average:	54	734	620	758	590	752	623
smpl. std. dev.:	54	31	4	15	17	17	21
spec. min., lbs/inch		300		300		300	

* Preliminary data from screening experiments, 1991
all data in units of lbs/inch
smpl. std. dev. = sample standard deviation
c:\qpw\data\outdoor\fab-data.wb3
April 2, 1996

Table 12. Breaking Strength of Coated Fabric Sections
Effect of Composition

Elast. No.	Exposure months	Blank fill average	Blank fill st. dev.	Blank warp average	Blank warp st. dev.	Jet fuel fill average	Jet fuel fill st. dev.	Jet fuel warp average	Jet fuel warp st. dev.	Diesel fuel fill average	Diesel fuel fill st. dev.	Diesel fuel warp average	Diesel fuel warp st. dev.
E-1 *	0	758	-----	879	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-2 *	0	764	-----	724	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-3 *	0	624	-----	745	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-4 *	0	613	-----	743	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-5 *	0	567	-----	754	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-1	30	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-2	30	799	22	798	5	550	9	278	182	-----	-----	-----	-----
E-3	30	512	7	730	7	317	11	395	56	-----	-----	-----	-----
E-4	30	566	5	758	3	296	13	517	19	-----	-----	-----	-----
E-5	30	470	60	723	15	682	39	649	23	558	30	732	10
E-1	36	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-2	36	794	8	689	8	308	14	408	12	-----	-----	-----	-----
E-3	36	627	12	392	23	367	38	237	5	-----	-----	-----	-----
E-4	36	752	15	612	15	-----	-----	-----	-----	-----	-----	-----	-----
E-5	36	572	29	590	28	680	25	597	13	757	17	693	9
E-1	42	358	9	722	31	416	13	681	32	608	15	721	15
E-2	42	850	8	760	20	362	11	503	16	-----	-----	-----	-----
E-3	42	651	31	442	11	-----	-----	-----	-----	-----	-----	-----	-----
E-4	42	762	30	616	24	-----	-----	-----	-----	-----	-----	-----	-----
E-5	42	774	11	555	34	673	48	644	6	739	17	513	29
E-1	48	674	34	354	29	667	9	351	27	697	31	413	13
E-2	48	833	27	706	26	-----	-----	-----	-----	-----	-----	-----	-----
E-3	48	689	46	381	4	-----	-----	-----	-----	-----	-----	-----	-----
E-4	48	578	2	734	16	-----	-----	-----	-----	-----	-----	-----	-----
E-5	48	756	23	586	14	527	13	605	9	783	6	682	10
E-1	54	700	23	315	16	671	25	339	13	759	8	523	27
E-2	54	818	9	721	16	-----	-----	-----	-----	-----	-----	-----	-----
E-3	54	707	23	380	37	-----	-----	-----	-----	-----	-----	-----	-----
E-4	54	747	13	503	30	-----	-----	-----	-----	-----	-----	-----	-----
E-5	54	734	31	620	4	758	15	590	17	752	17	623	21
E-1	60	701	34	340	29	727	24	570	25	747	24	595	17
E-1	66	727	19	385	15	617	14	562	29	650	46	398	37

* Preliminary data from screening experiments, 1991
all data in units of lbs/inch
c:\quattro7\..\outdoor\fabric.wb3
May 14, 1997

Table 13. Breaking Strength of Coated Fabric Sections
Effect of Time

Elast. No.	Exposure, months	Blank fill average	Blank fill st. dev.	Blank warp average	Blank warp st. dev.	Jet fuel fill average	Jet fuel fill st. dev.	Jet fuel warp average	Jet fuel warp st. dev.	Diesel fuel fill average	Diesel fuel fill st. dev.	Diesel fuel warp average	Diesel fuel warp st. dev.
E-1 *	0	758	-----	879	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-1	42	358	9	722	31	416	13	681	32	608	15	721	15
E-1	48	674	34	354	29	667	9	351	27	697	31	413	13
E-1	54	700	23	315	16	671	25	339	13	759	8	523	27
E-1	60	701	34	340	29	727	24	570	25	747	24	595	17
E-1	66	727	19	385	15	617	14	562	29	650	46	398	37
E-2 *	0	764	-----	724	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-2	30	799	22	798	5	550	9	278	182	-----	-----	-----	-----
E-2	36	794	8	689	8	308	14	408	12	-----	-----	-----	-----
E-2	42	850	8	760	20	362	11	503	16	-----	-----	-----	-----
E-2	48	833	27	706	26	-----	-----	-----	-----	-----	-----	-----	-----
E-2	54	818	9	721	16	-----	-----	-----	-----	-----	-----	-----	-----
E-3 *	0	624	-----	745	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-3	30	512	7	730	7	317	11	395	56	-----	-----	-----	-----
E-3	36	627	12	392	23	367	38	237	5	-----	-----	-----	-----
E-3	42	651	31	442	11	-----	-----	-----	-----	-----	-----	-----	-----
E-3	48	689	46	381	4	-----	-----	-----	-----	-----	-----	-----	-----
E-3	54	707	23	380	37	-----	-----	-----	-----	-----	-----	-----	-----
E-4 *	0	613	-----	743	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-4	30	566	5	758	3	296	13	517	19	-----	-----	-----	-----
E-4	36	752	15	612	15	-----	-----	-----	-----	-----	-----	-----	-----
E-4	42	762	30	616	24	-----	-----	-----	-----	-----	-----	-----	-----
E-4	48	578	2	734	16	-----	-----	-----	-----	-----	-----	-----	-----
E-4	54	747	13	503	30	-----	-----	-----	-----	-----	-----	-----	-----
E-5 *	0	567	-----	754	-----	-----	-----	-----	-----	-----	-----	-----	-----
E-5	30	470	60	723	15	682	39	649	23	558	30	732	10
E-5	36	572	29	590	28	680	25	597	13	757	17	693	9
E-5	42	774	11	555	34	673	48	644	6	739	17	513	29
E-5	48	756	23	586	14	527	13	605	9	783	6	682	10
E-5	54	734	31	620	4	758	15	590	17	752	17	623	21

* Preliminary data from screening experiments, 1991
all data in units of lbs/inch
c:\quattro7\..\outdoor\fabric.wb3
May 14, 1997

Table 14. STEAM JET GUM CONTENT OF FUELS FROM PILLOW TANKS

Elastomer ID	Exposure months	Steam Jet Gum, mg/100 mL Diesel Fuel	Jet Fuel
E-1	0	19.5	3.2
E-1	6	56.1	35.4
E-1	12	99.8	69.2
E-1	18	97.2	70.5
E-1	24	134.6	97.7
E-1	30	171.2	117.3
E-1	36	223.8	128.0
E-1	42	200.7	128.5
E-1	48	179.4	106.8
E-1	54	145.7	115.8
E-1	60	167.7	95.5
E-1	66	308.4	147.2
E-2	0	19.5	3.2
E-2	6	22.9	4.7
E-2	12	54.8	21.6
E-2	18	77.9	18.3
E-2	24	181.9	33.5
E-2	30	216.7	42.9
E-2	36	249.6	22.7
E-2	42	-----	14.1
E-2	48	-----	-----
E-2	54	-----	-----
E-3	0	19.5	3.2
E-3	6	82.0	29.8
E-3	12	158.7	94.1
E-3	18	164.9	71.2
E-3	24	215.9	114.7
E-3	30	270.5	175.4
E-3	36	311.7	132.4
E-3	42	-----	-----
E-3	48	-----	-----
E-3	54	-----	-----
E-4	0	19.5	3.2
E-4	6	18.5	6.4
E-4	12	169.7	18.1
E-4	18	145.8	16.4
E-4	24	170.1	13.3
E-4	30	-----	51.2
E-4	36	-----	-----
E-4	42	-----	-----
E-4	48	-----	-----
E-4	54	-----	-----
E-5	0	19.5	3.2
E-5	6	36.3	9.7
E-5	12	56.9	24.3
E-5	18	133.6	16.7
E-5	24	93.2	25.7
E-5	30	94.0	50.9
E-5	36	144.2	21.1
E-5	42	85.0	23.2
E-5	48	120.1	19.0
E-5	54	479.6	25.1

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FIGURES

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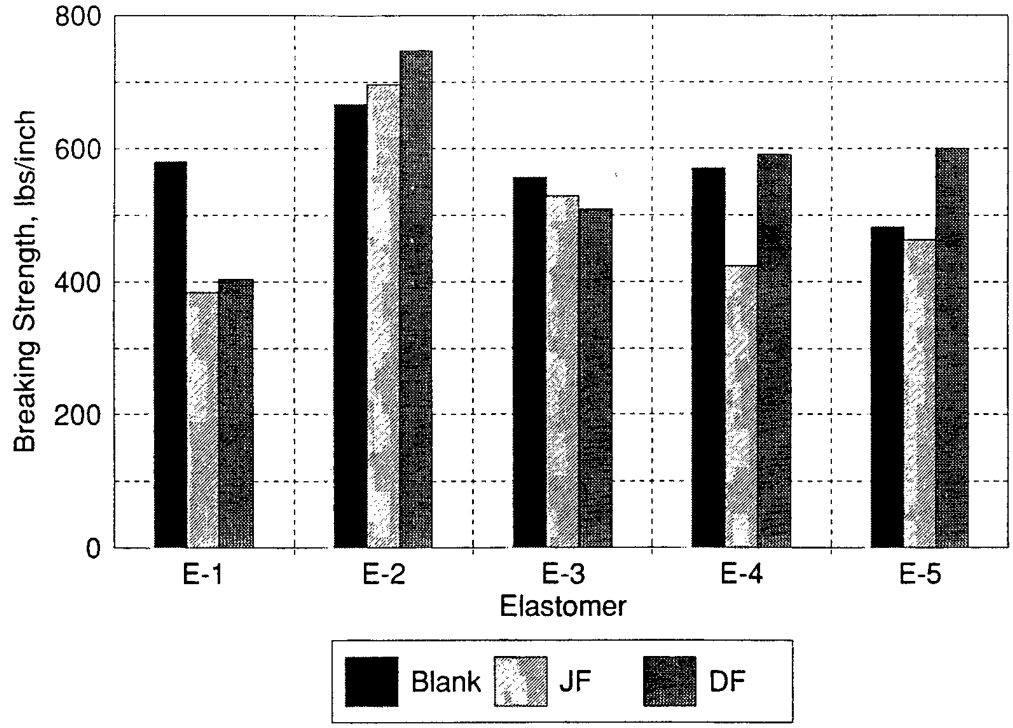

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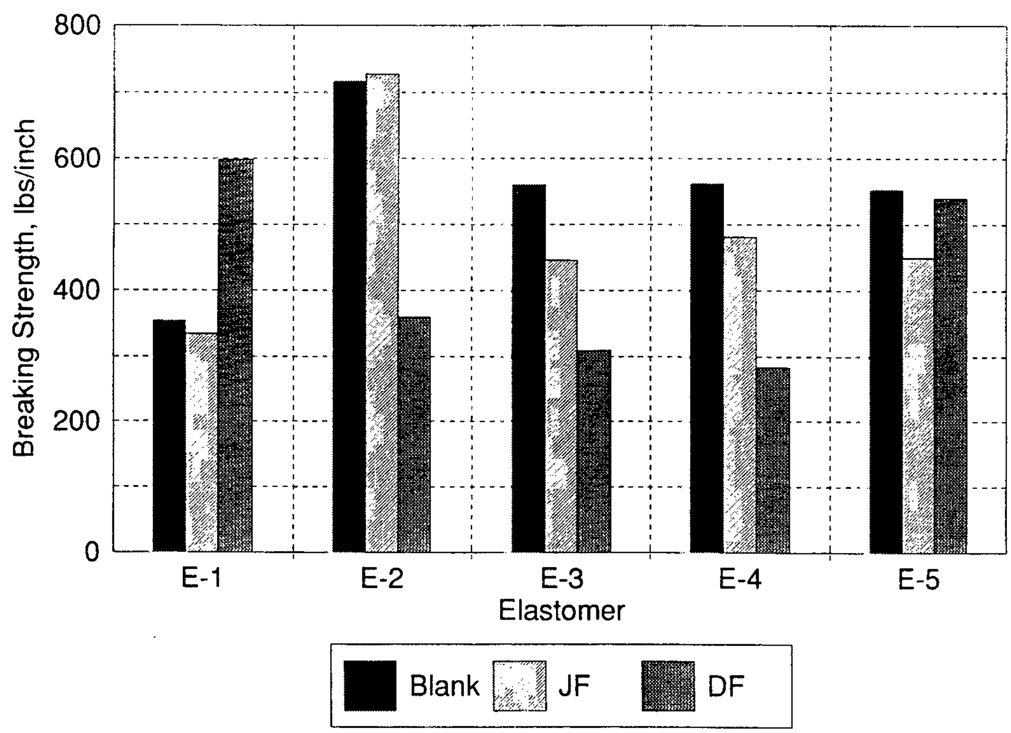

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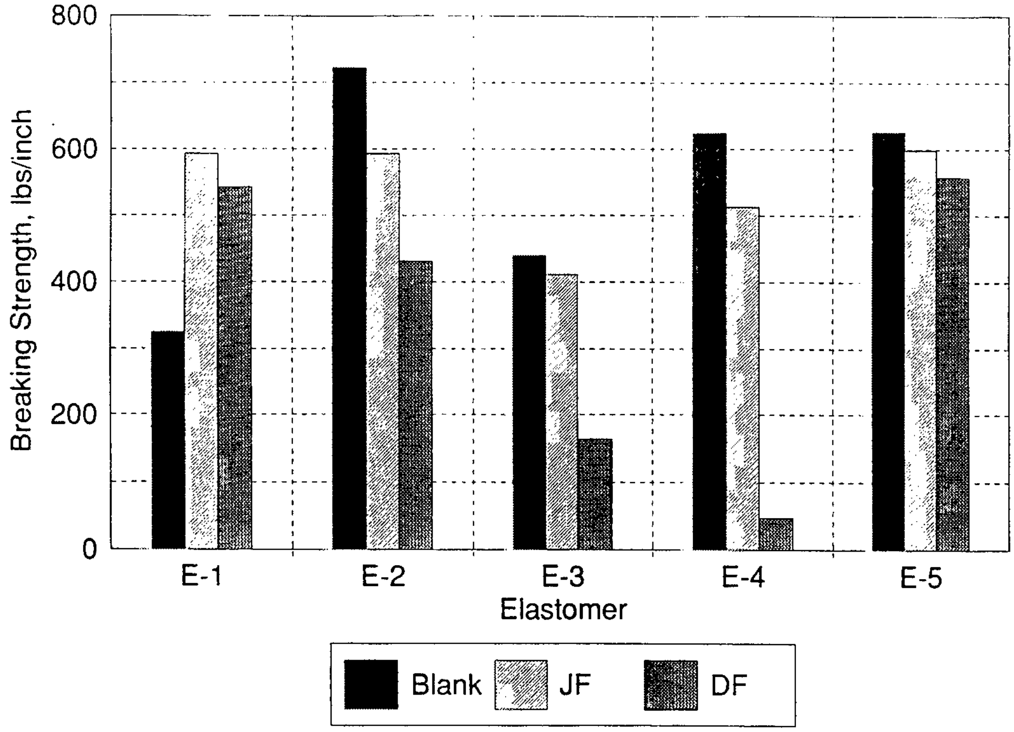

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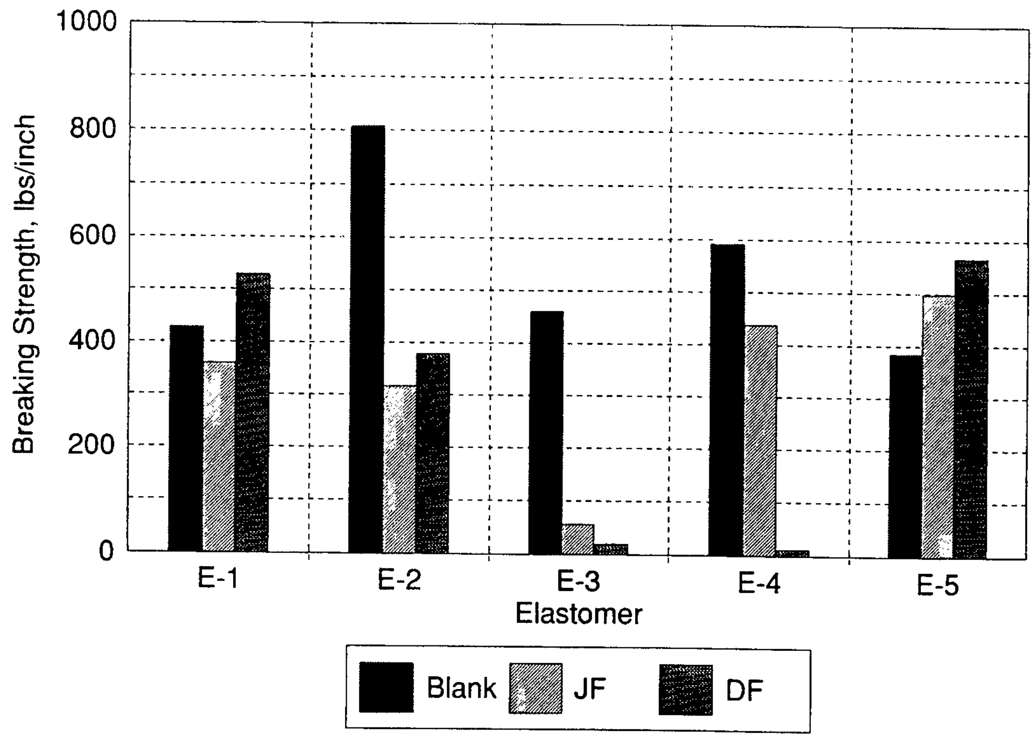

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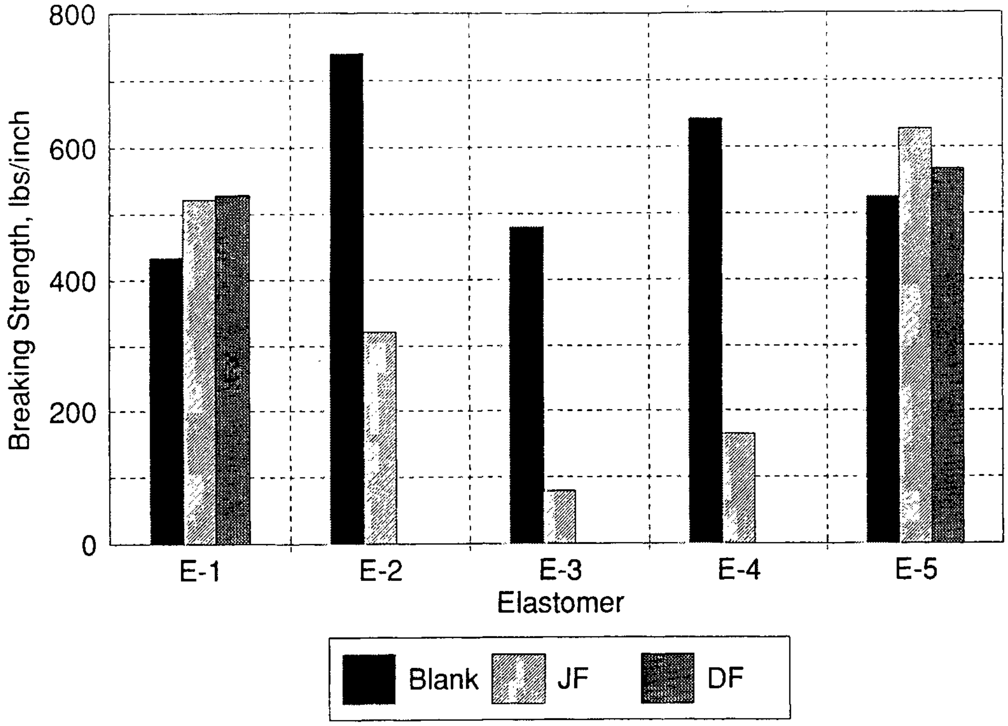

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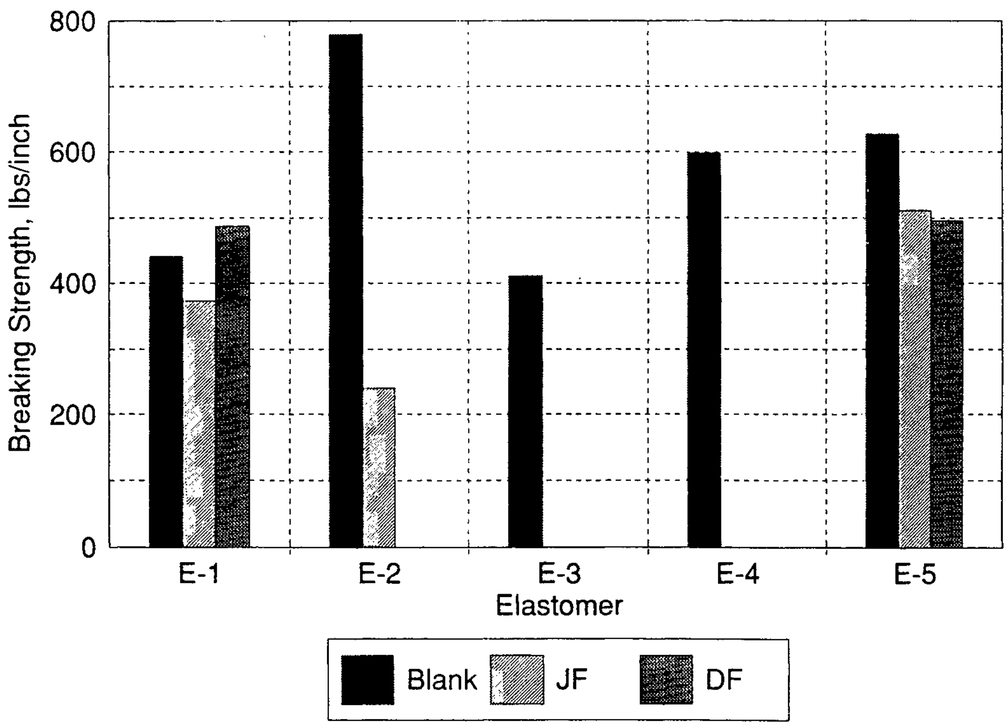

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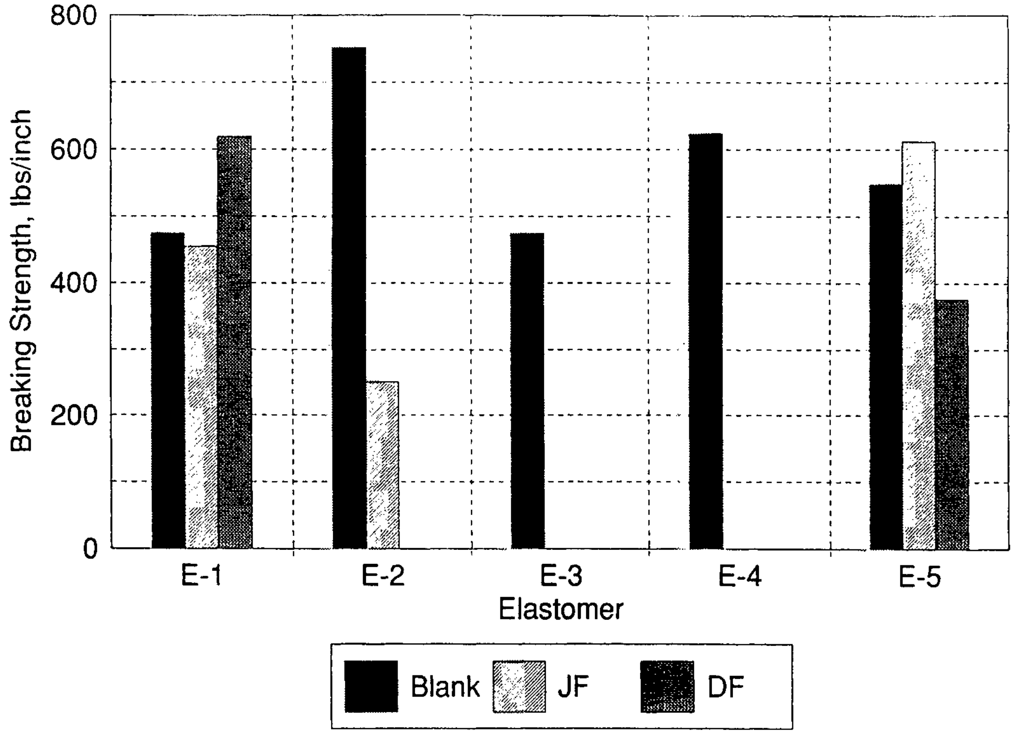

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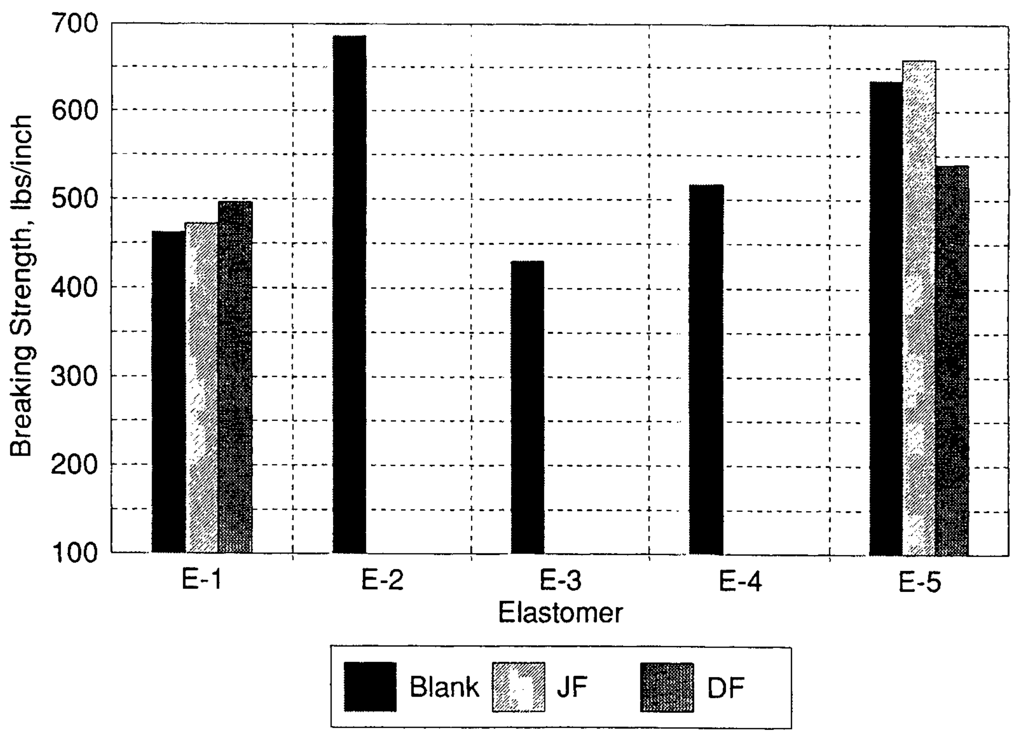

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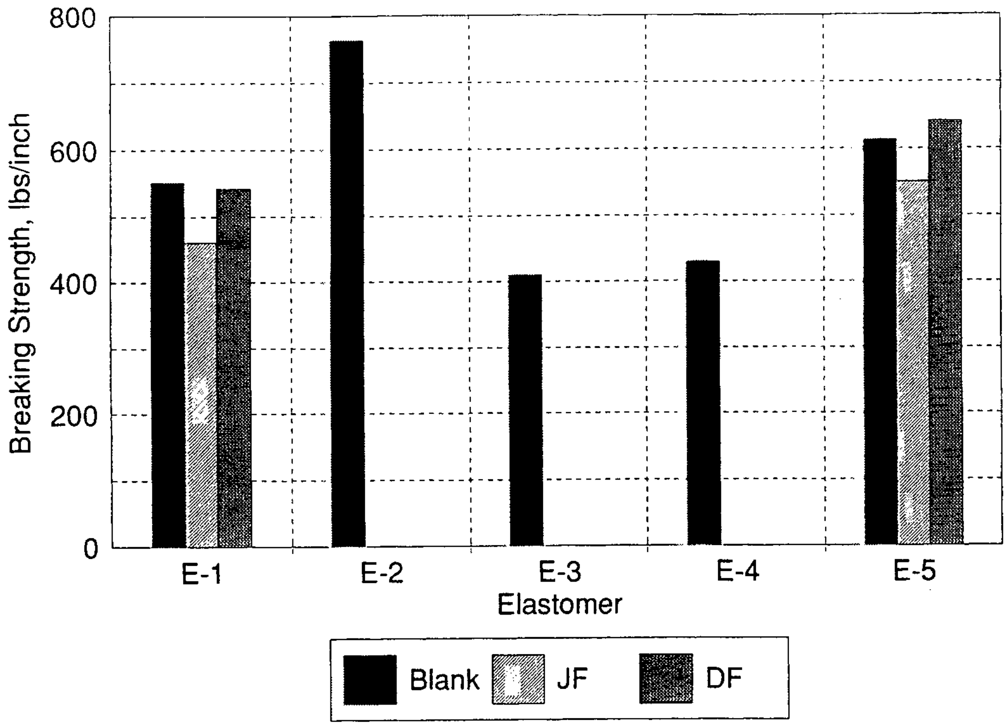

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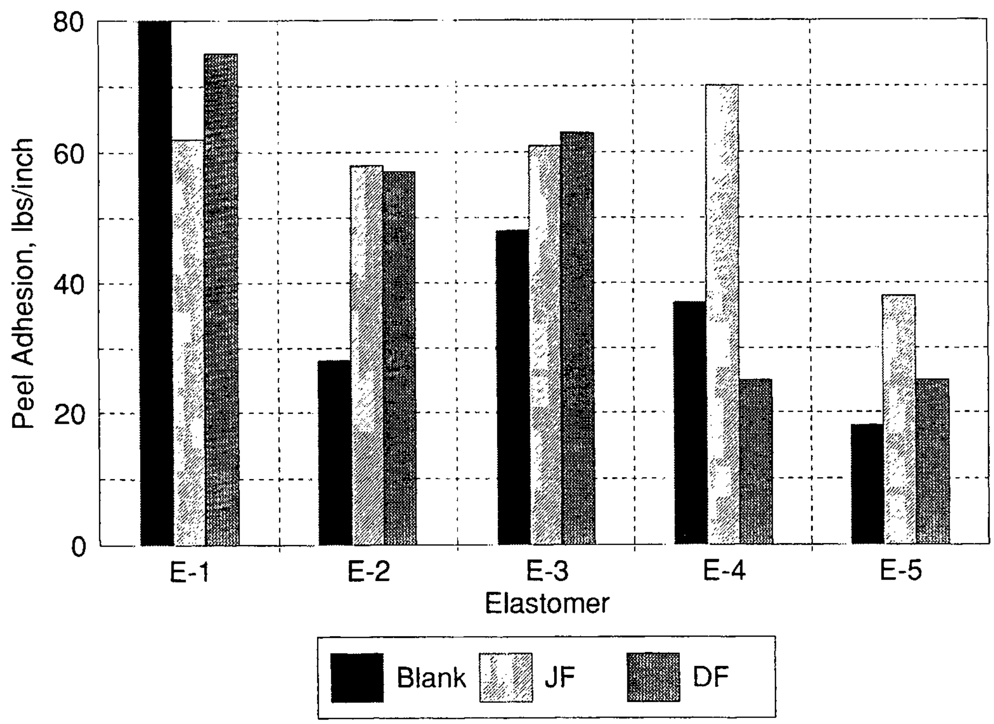

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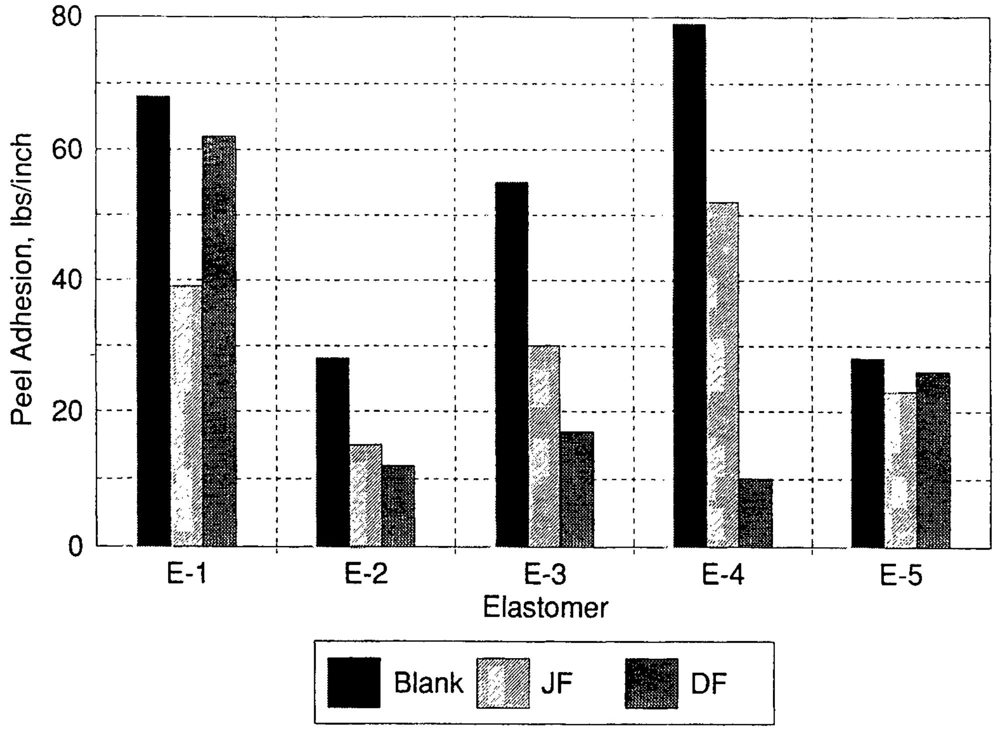

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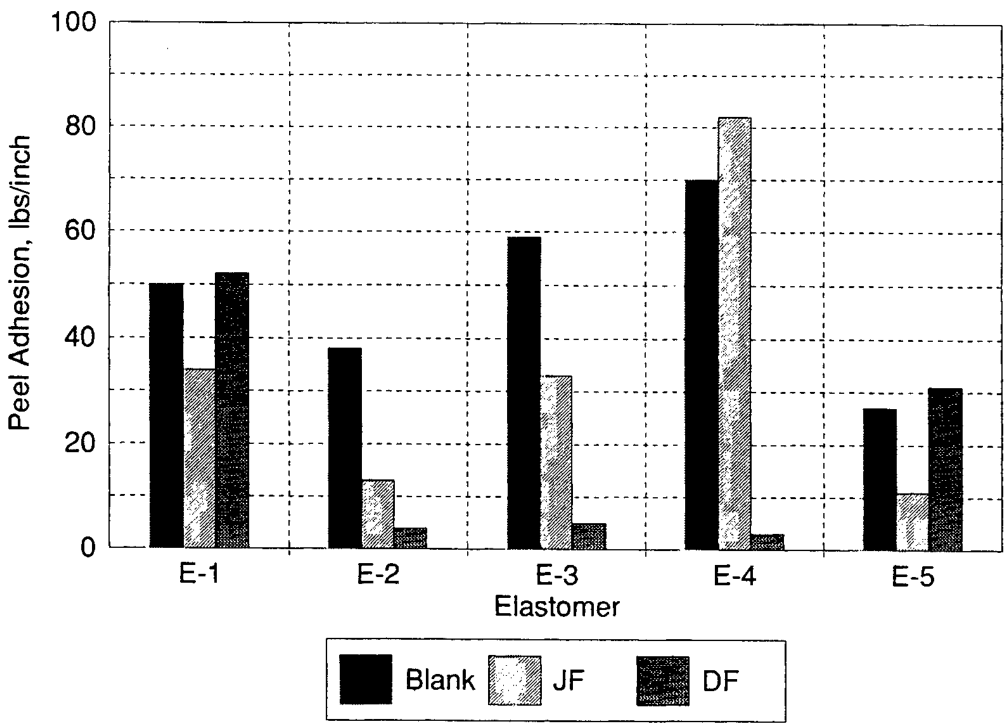

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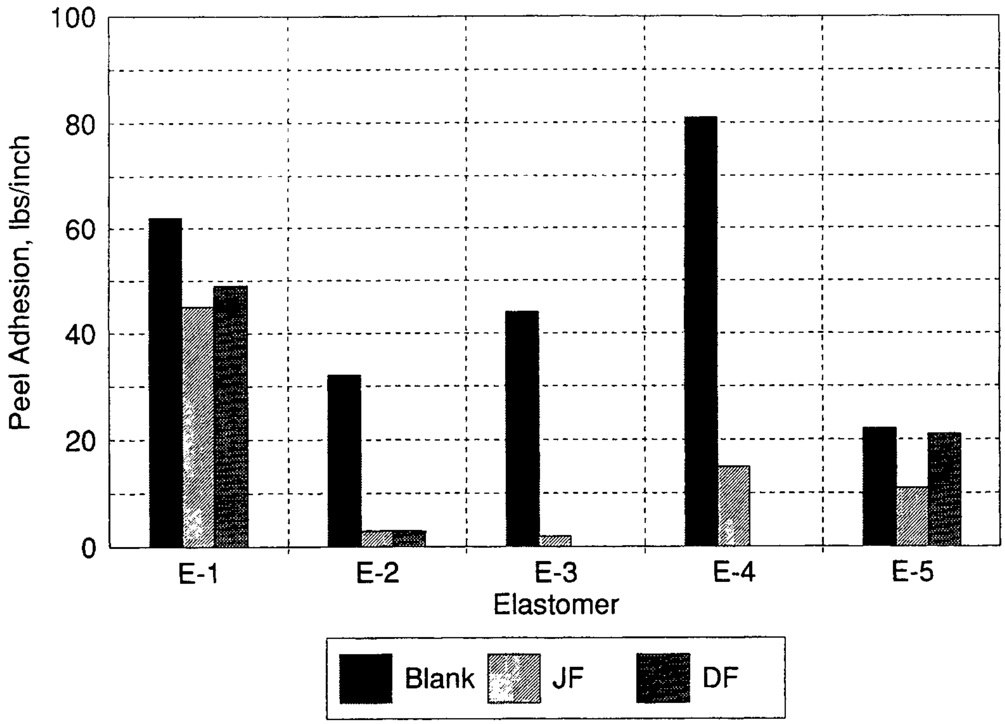

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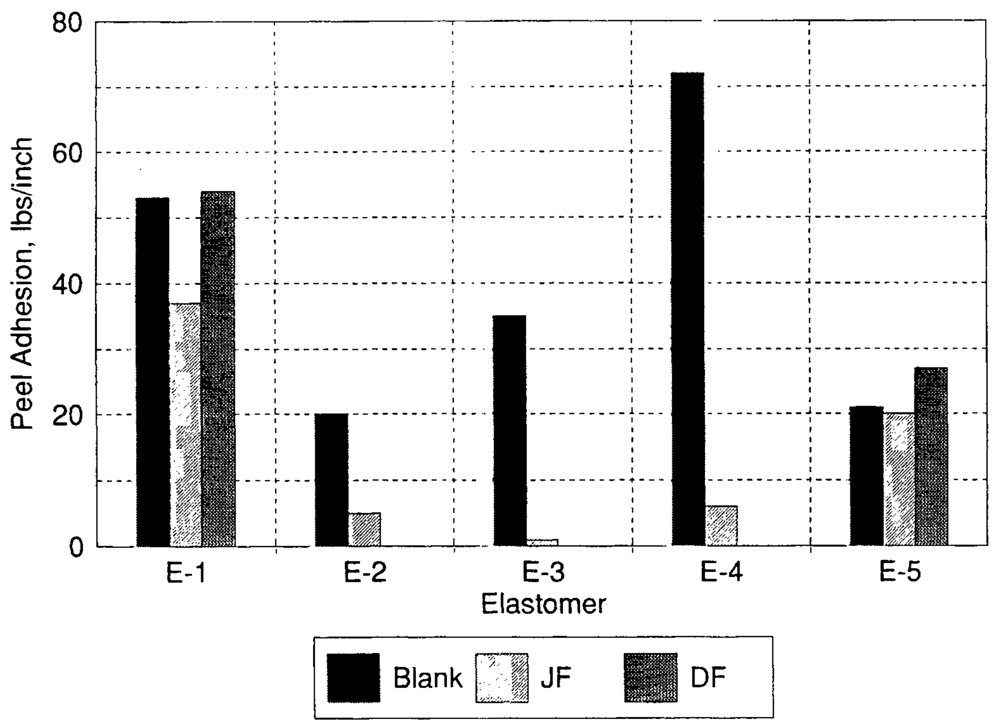

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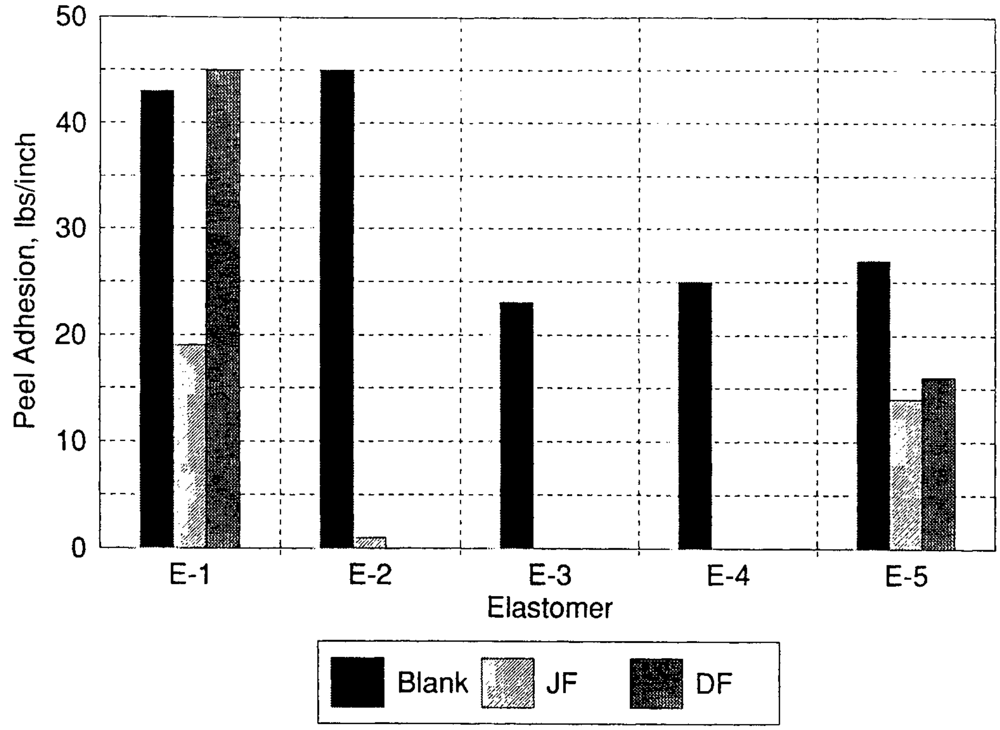

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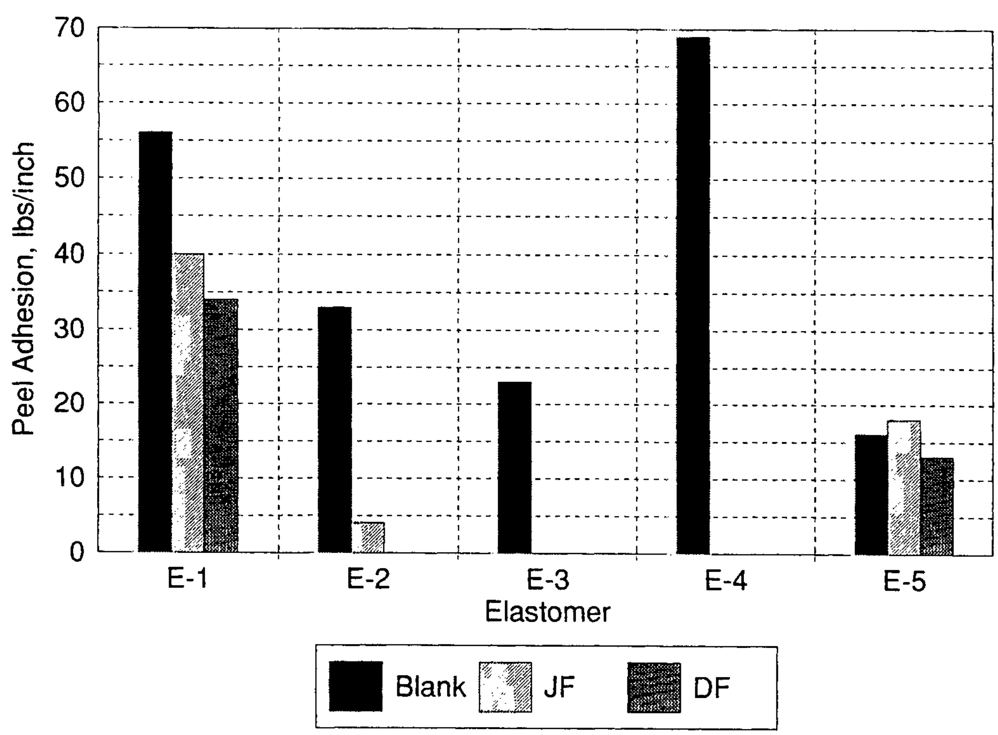

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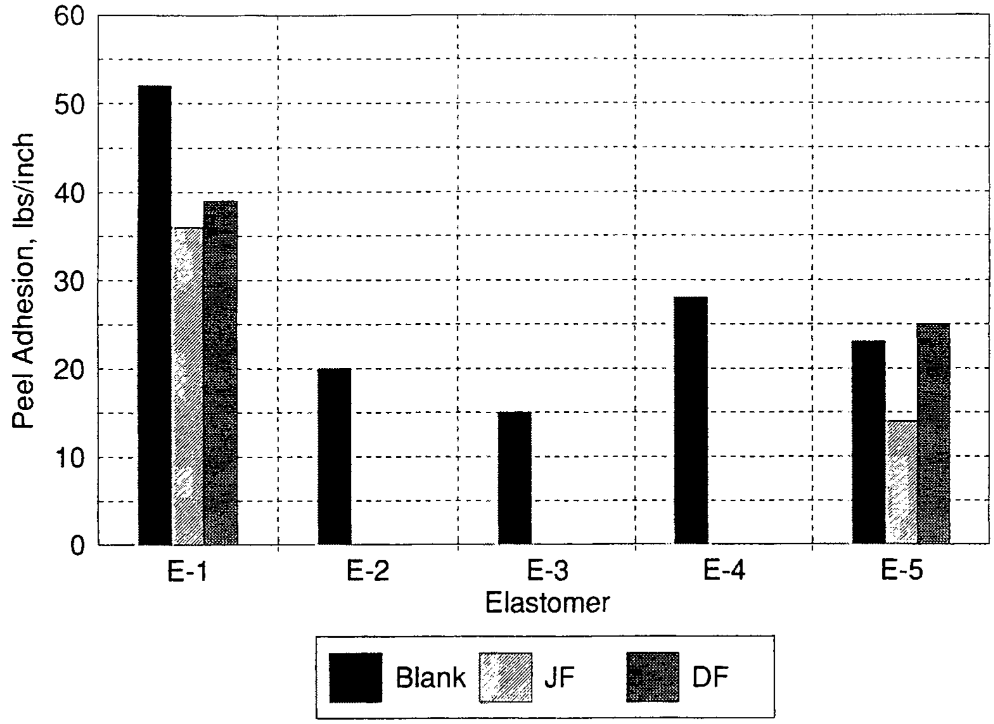

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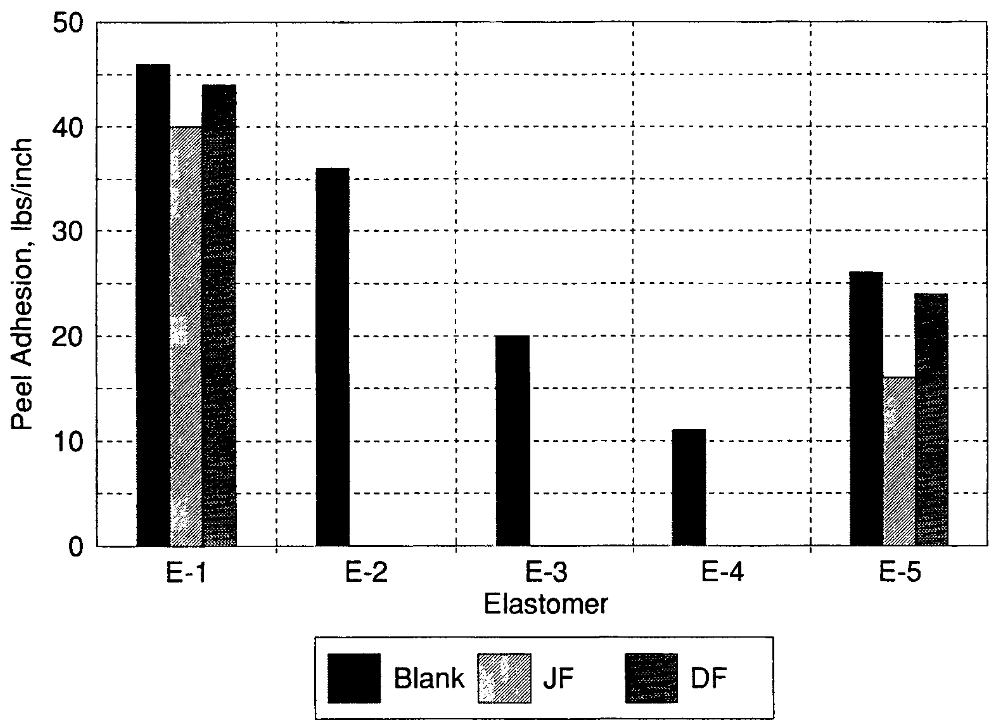

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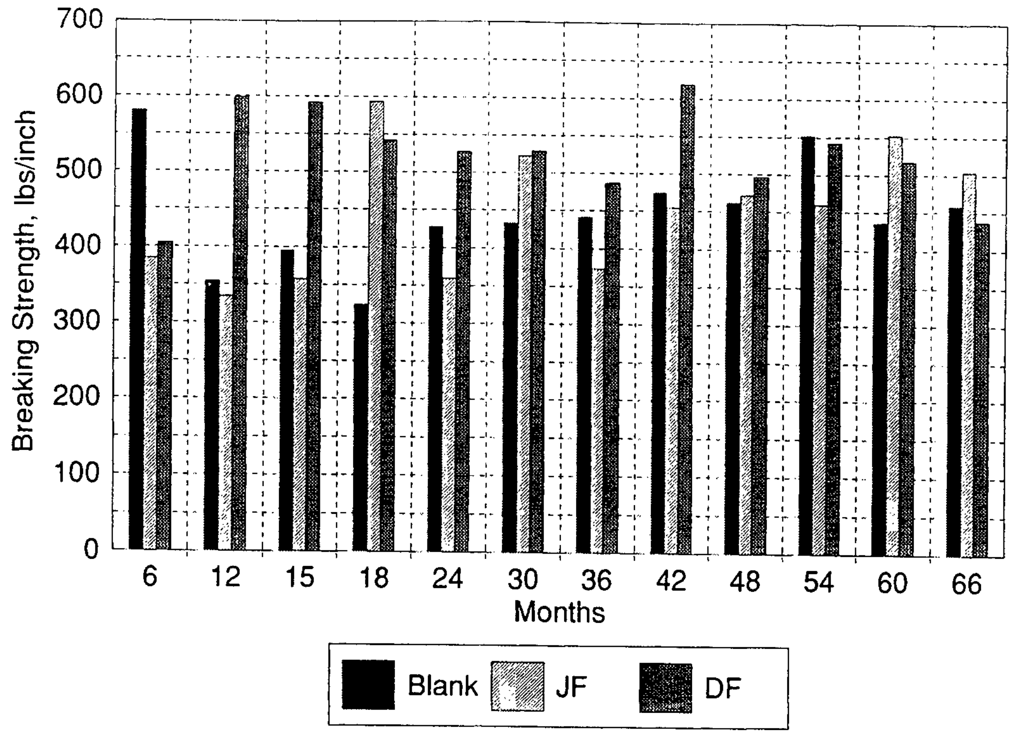

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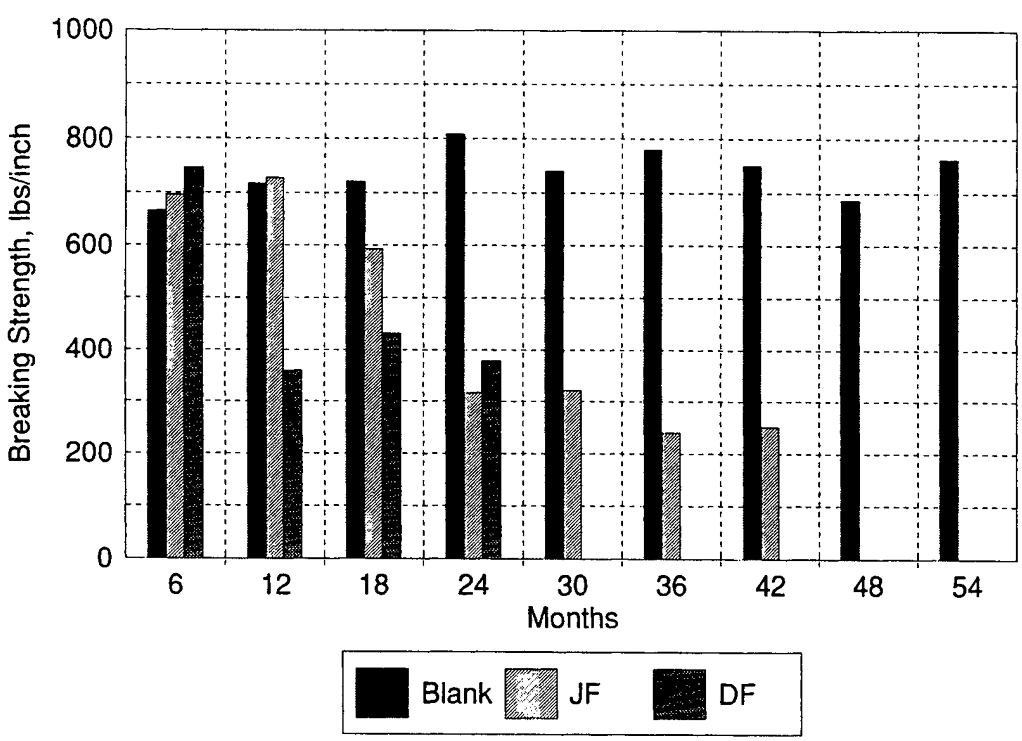

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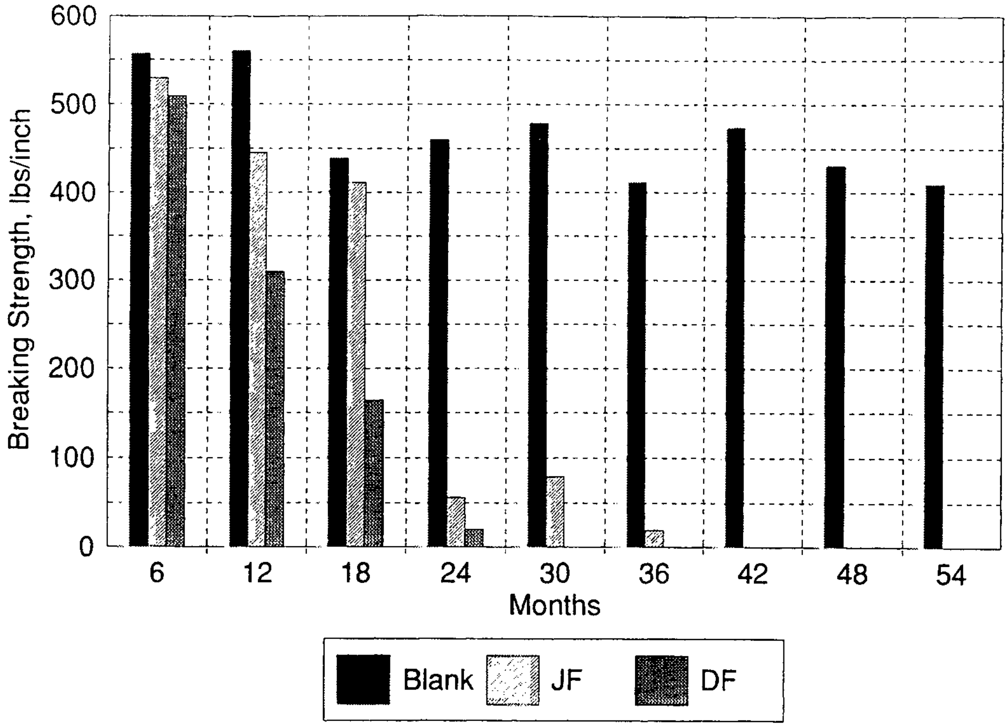

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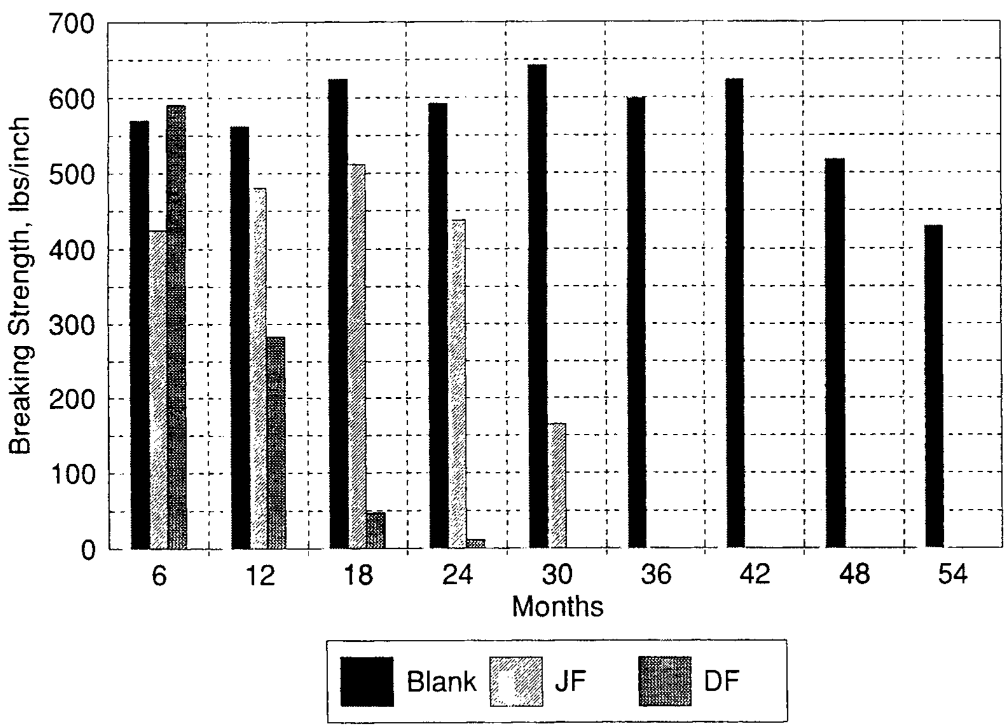

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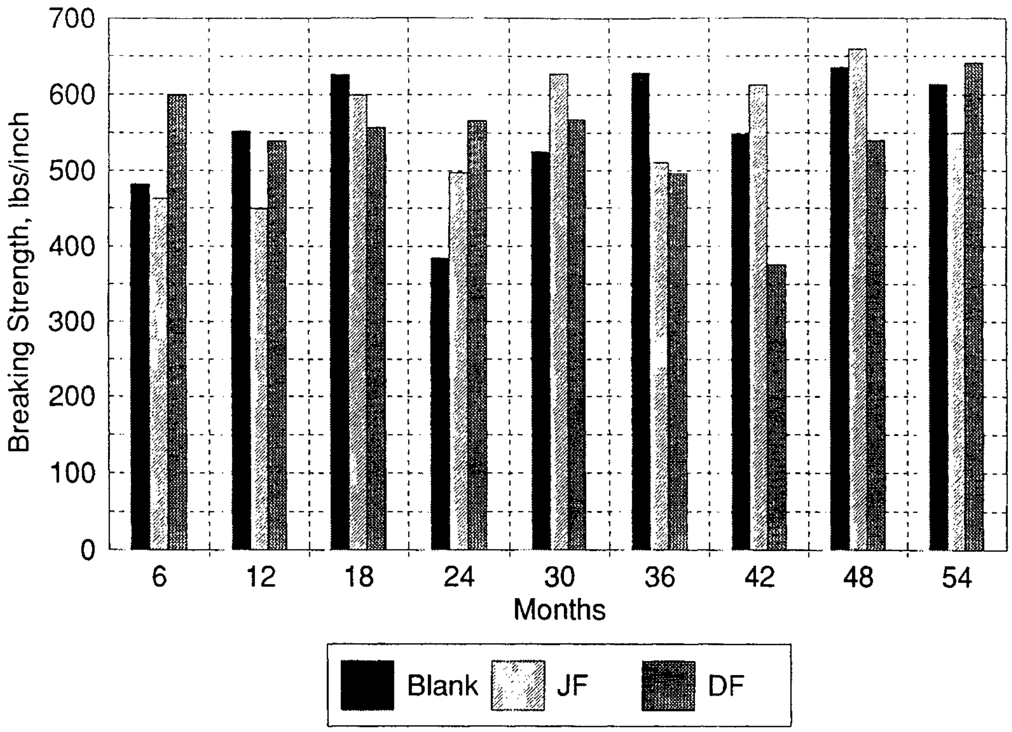

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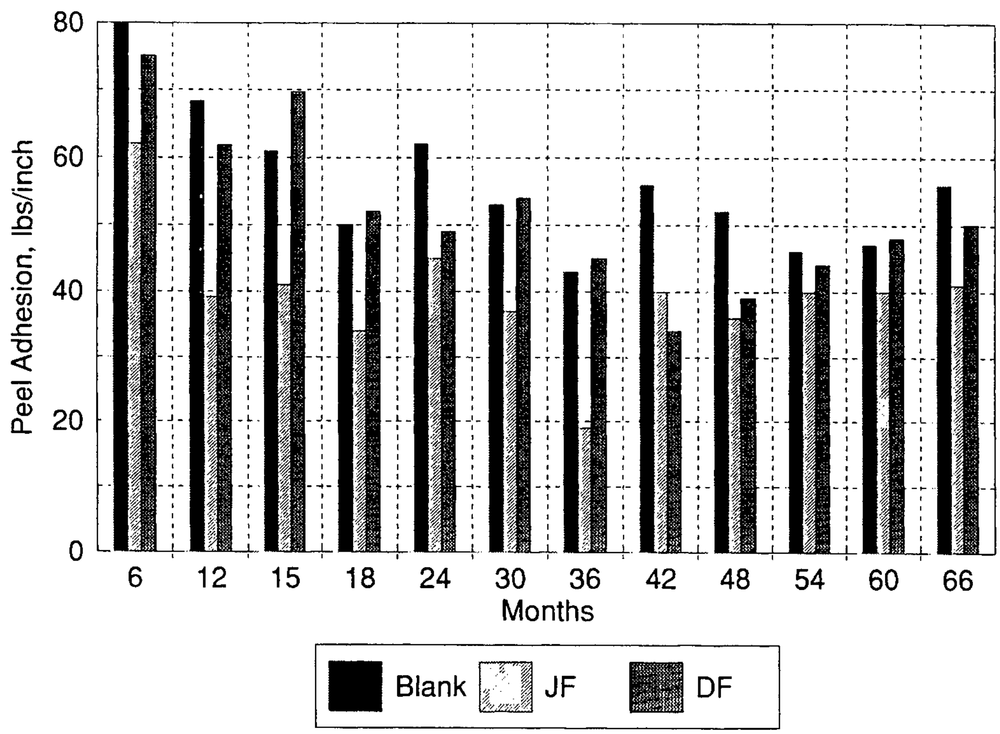

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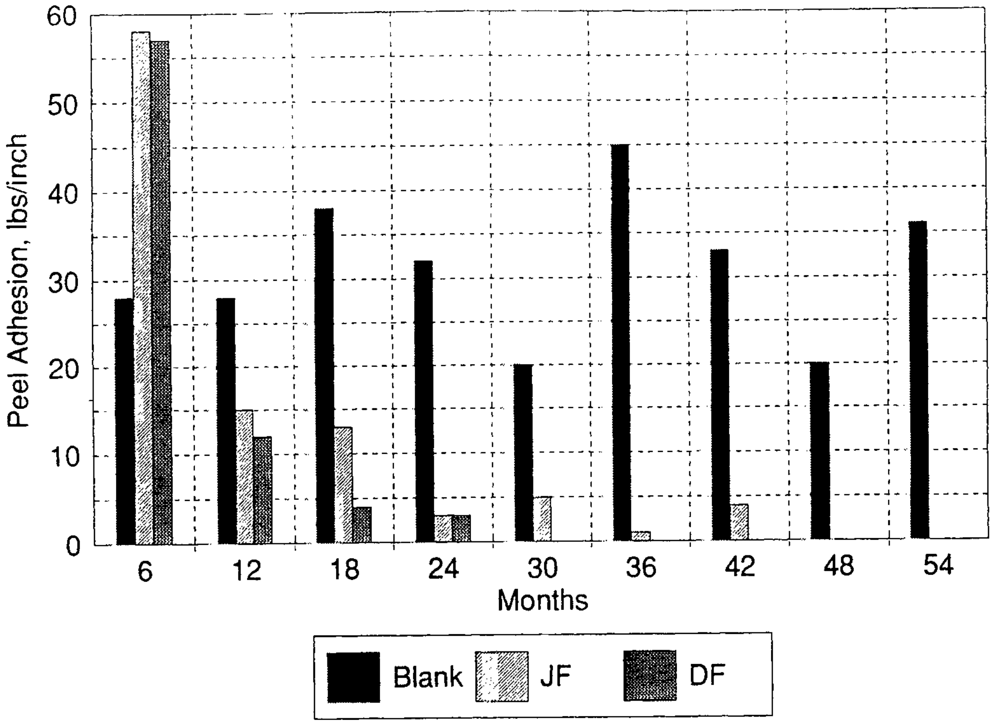

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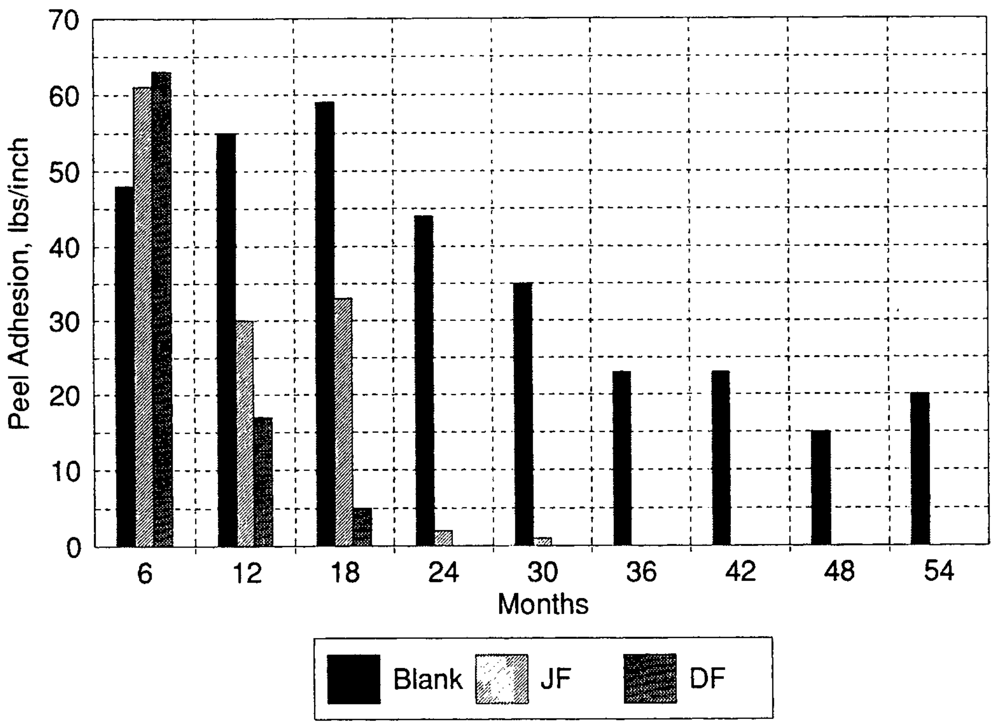

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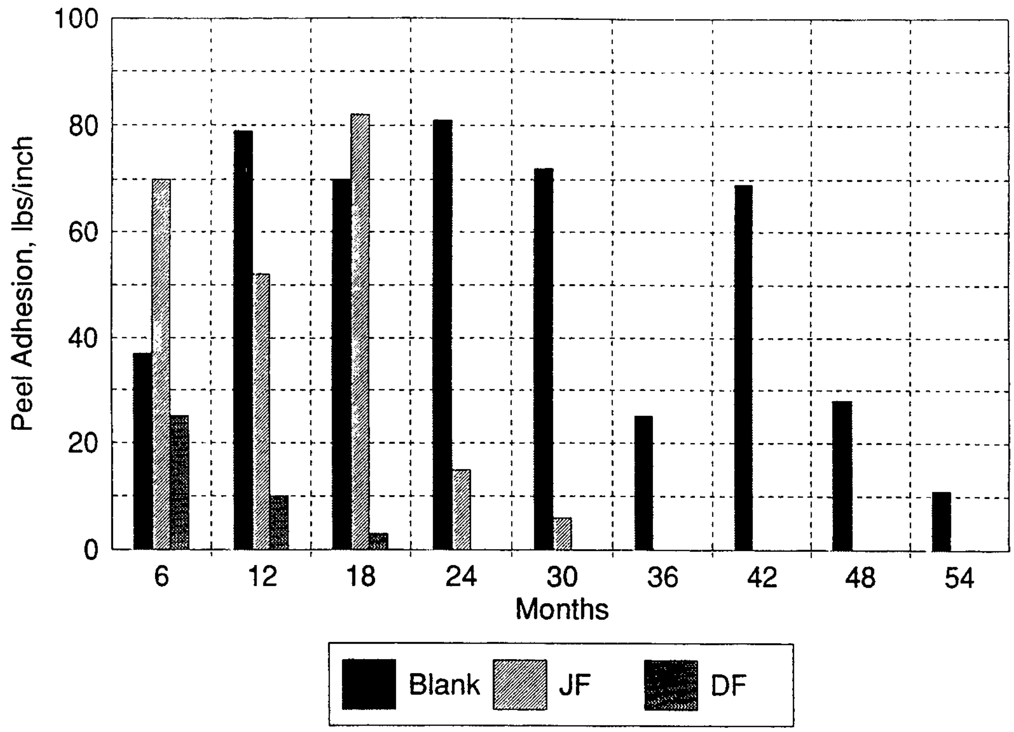

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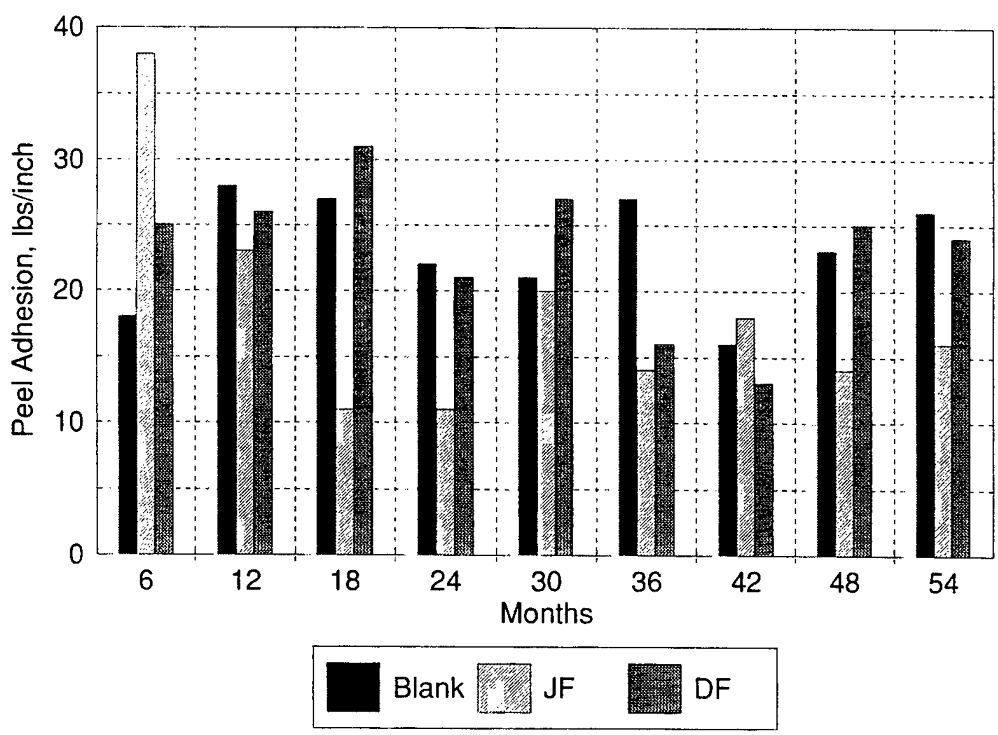

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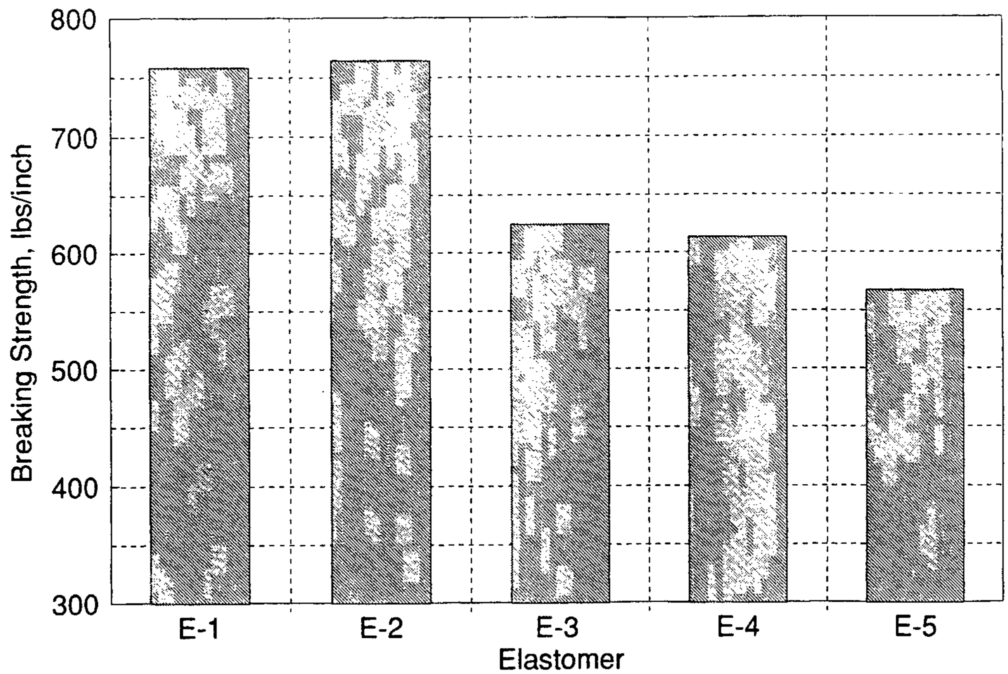

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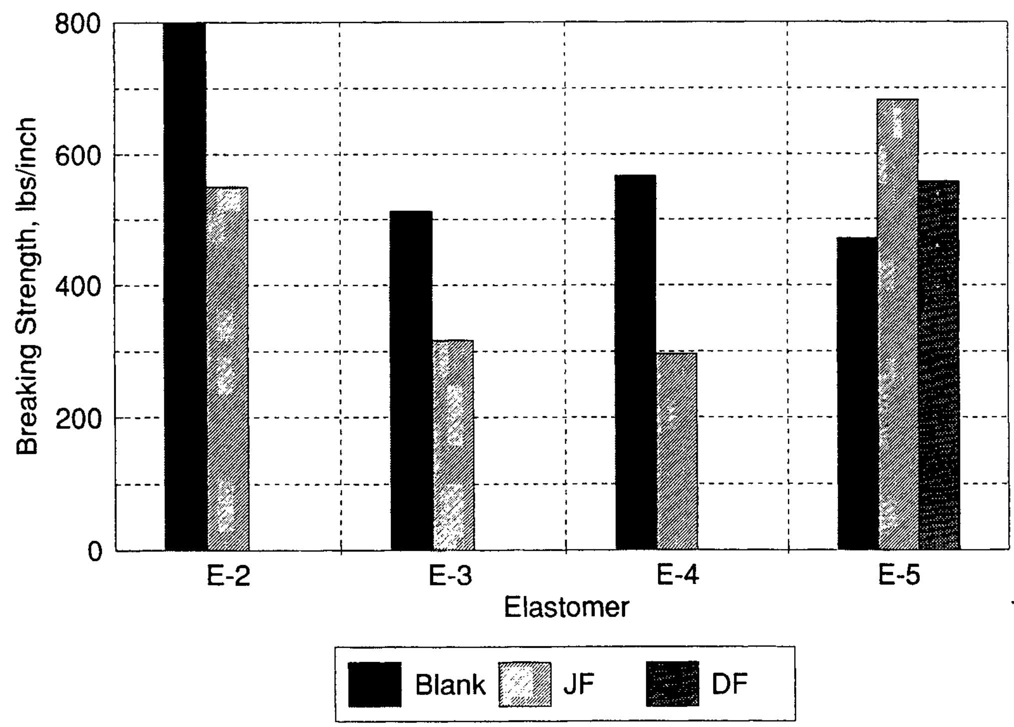

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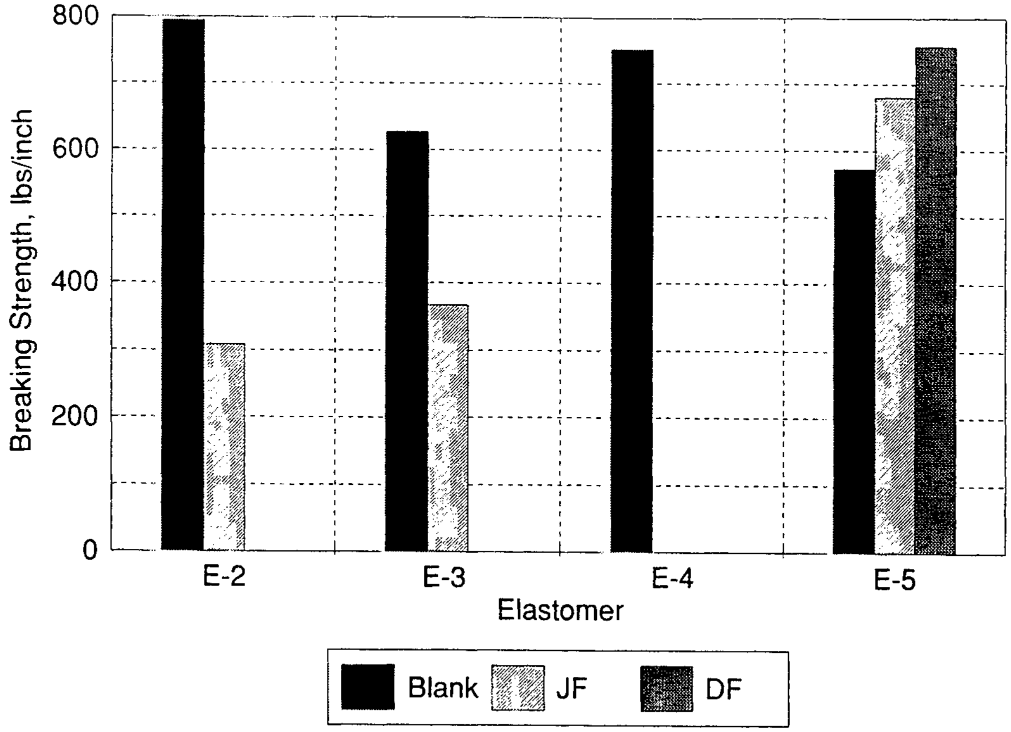

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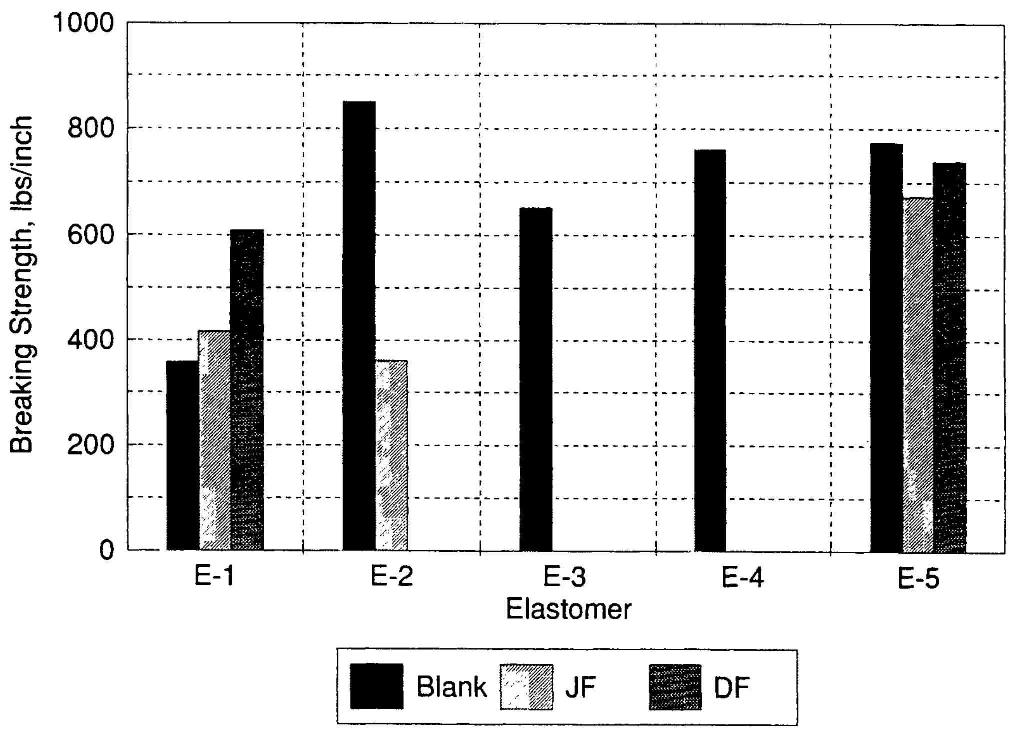

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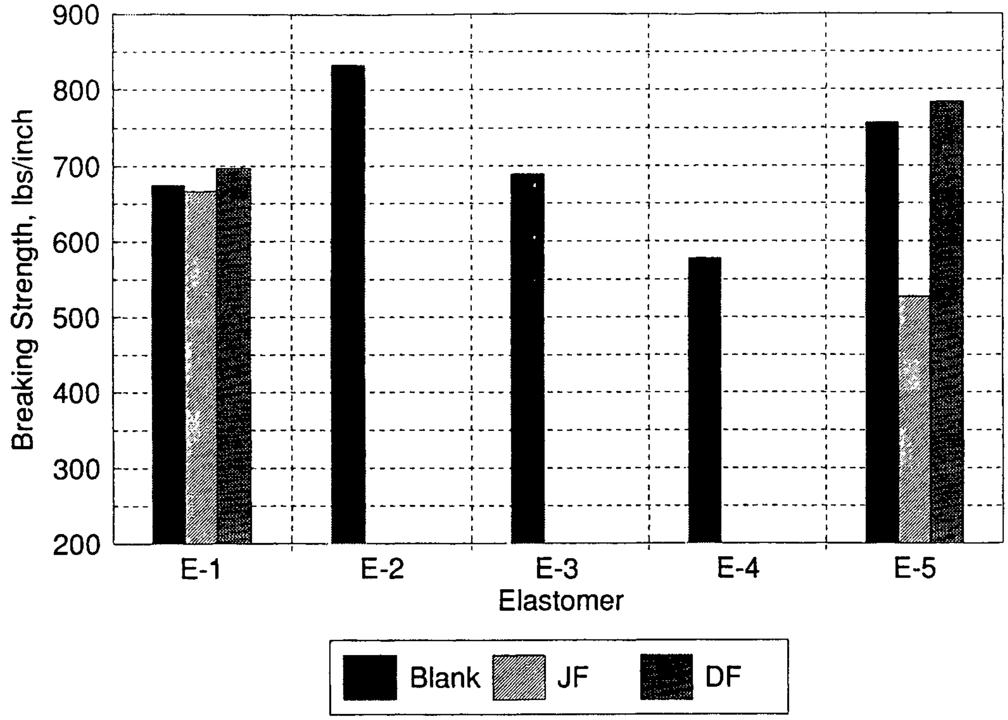

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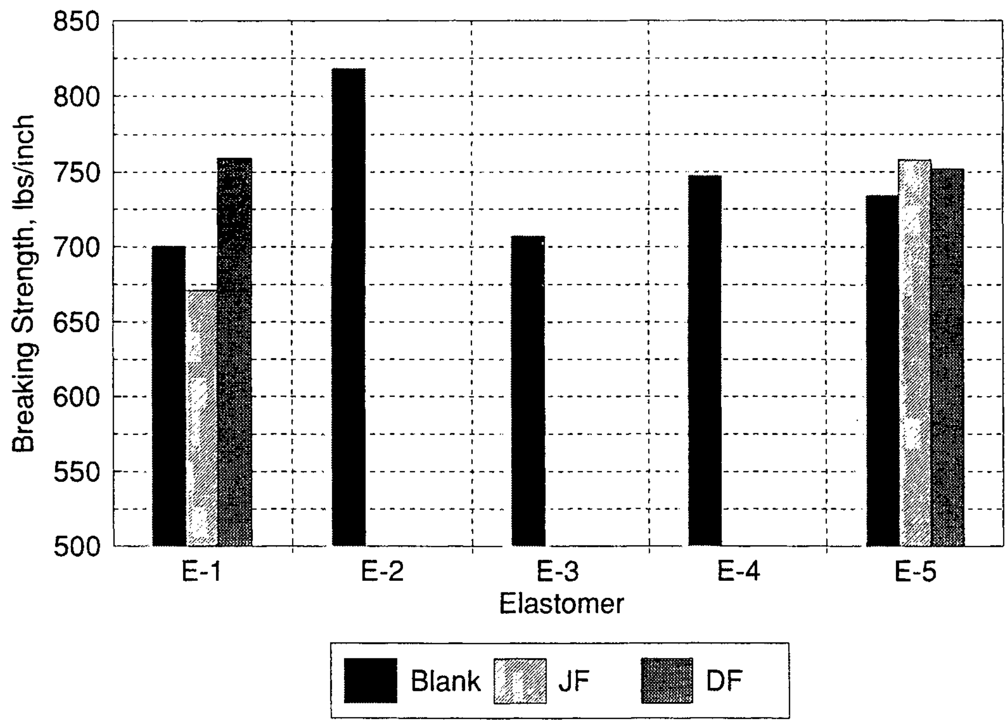

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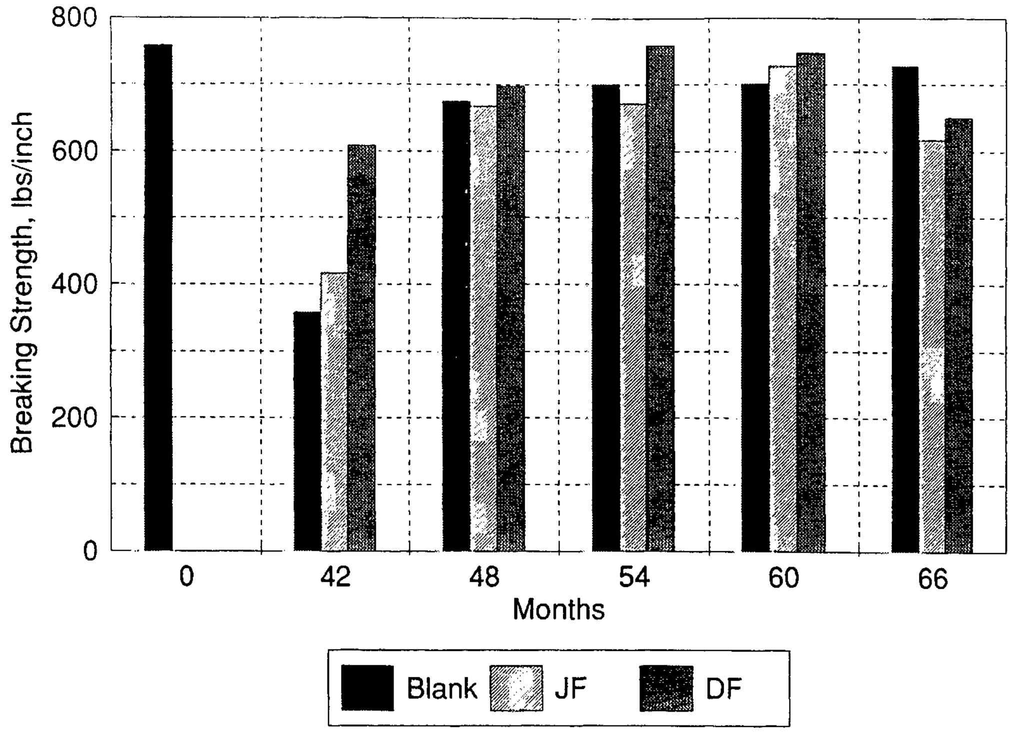

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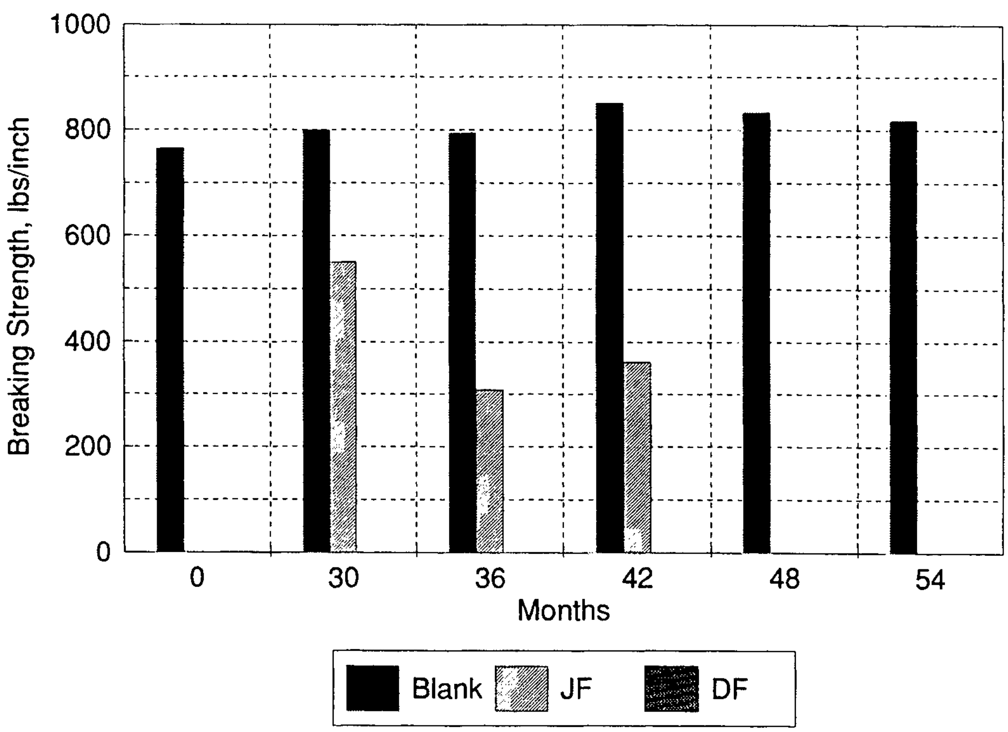

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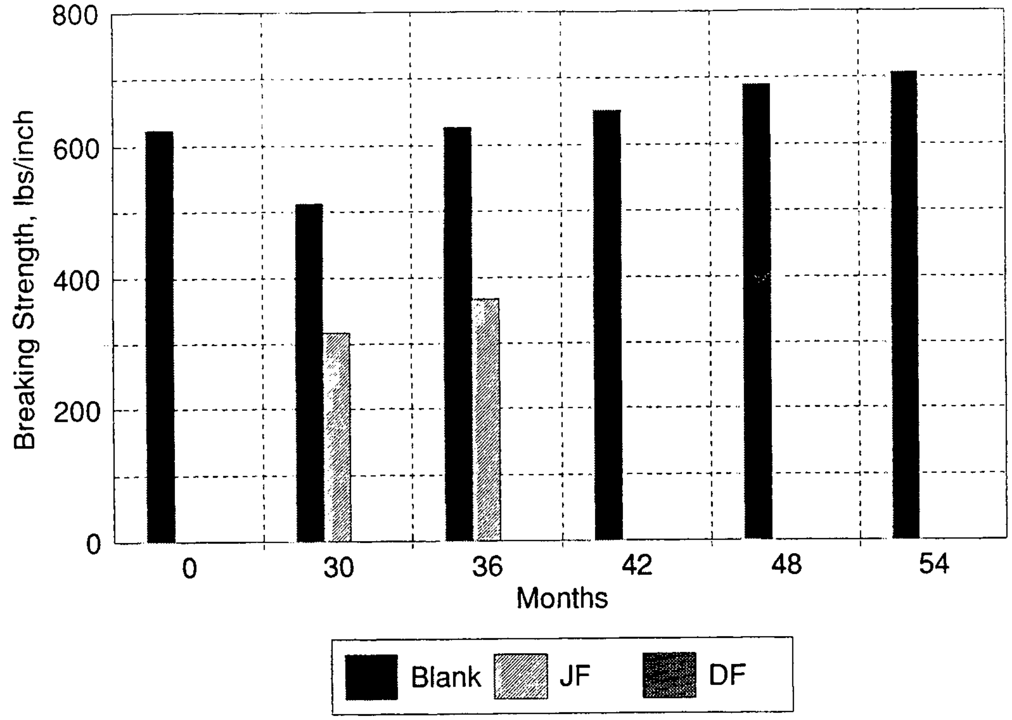

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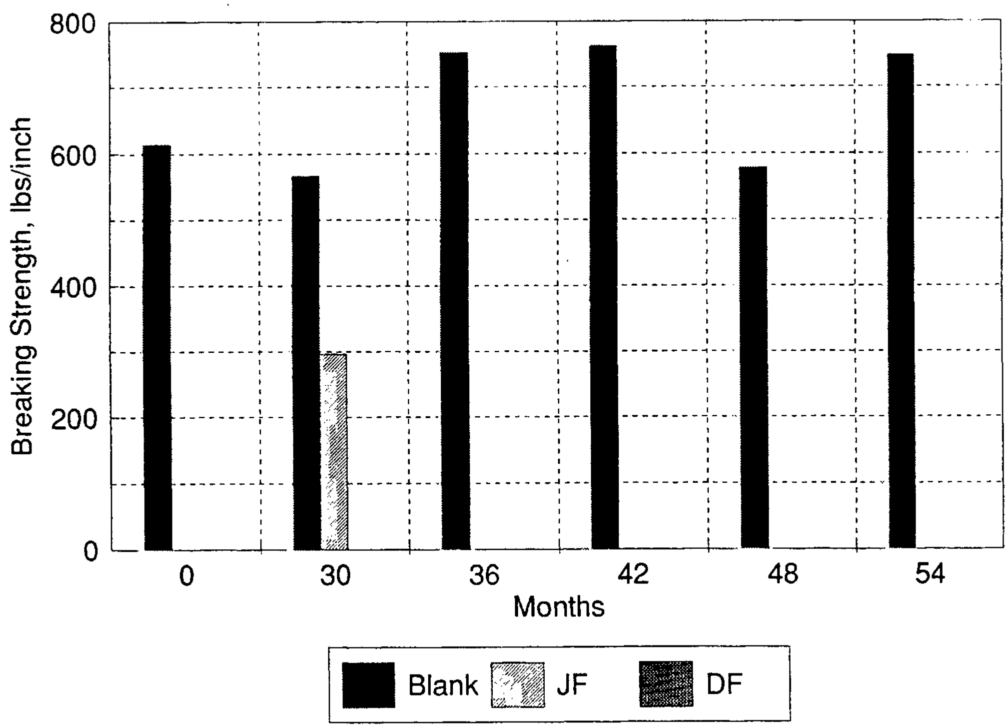

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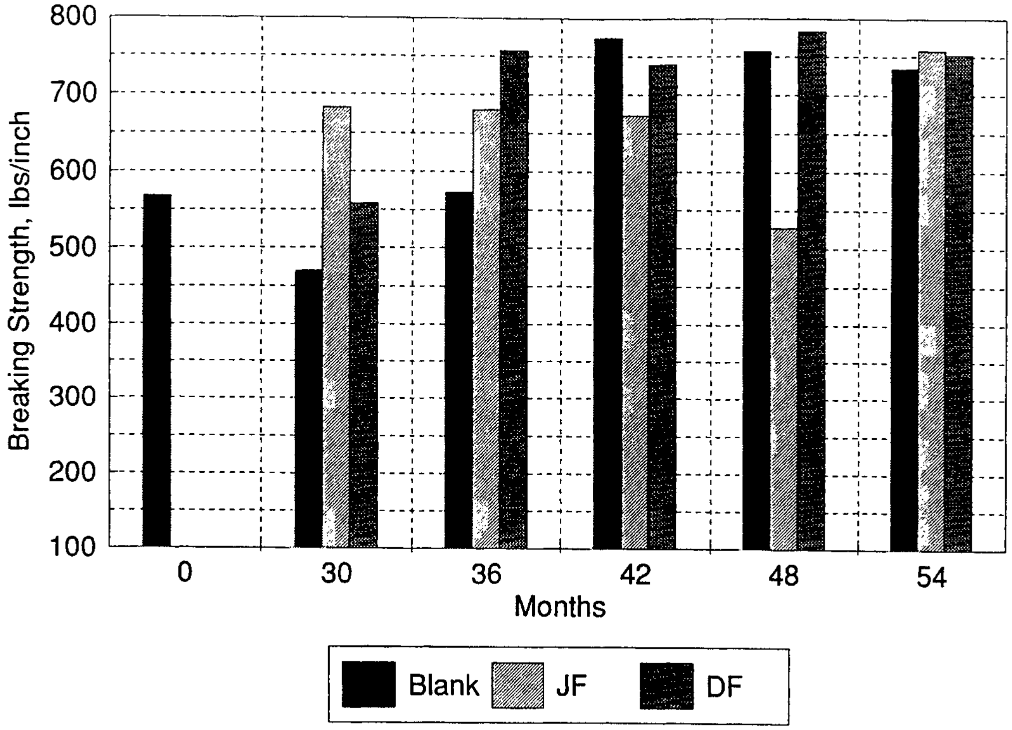

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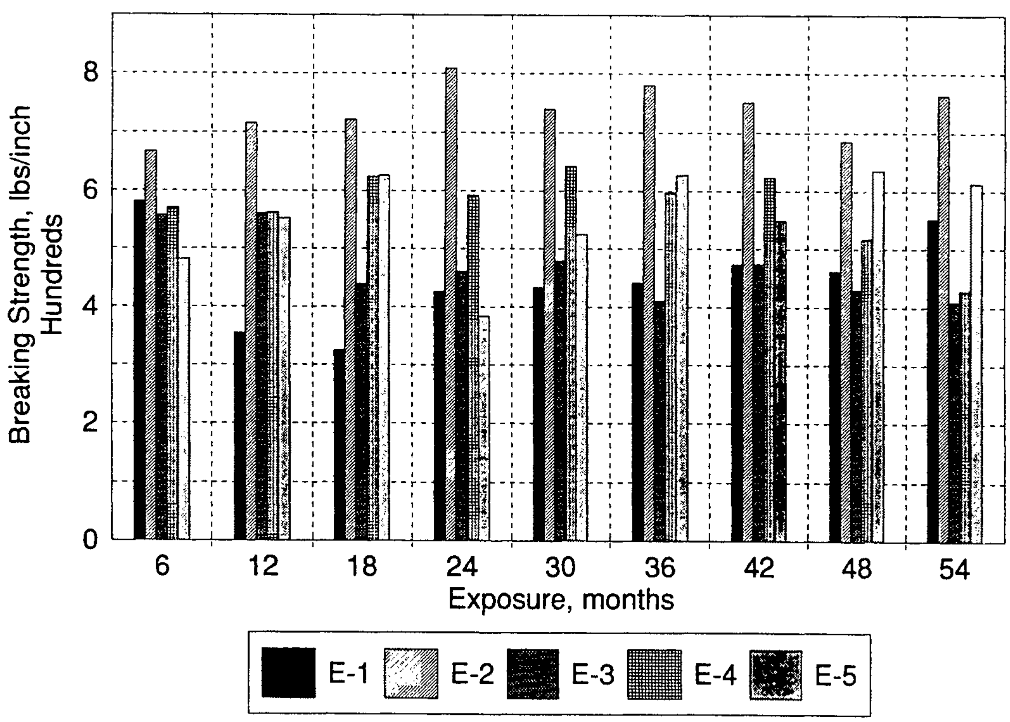

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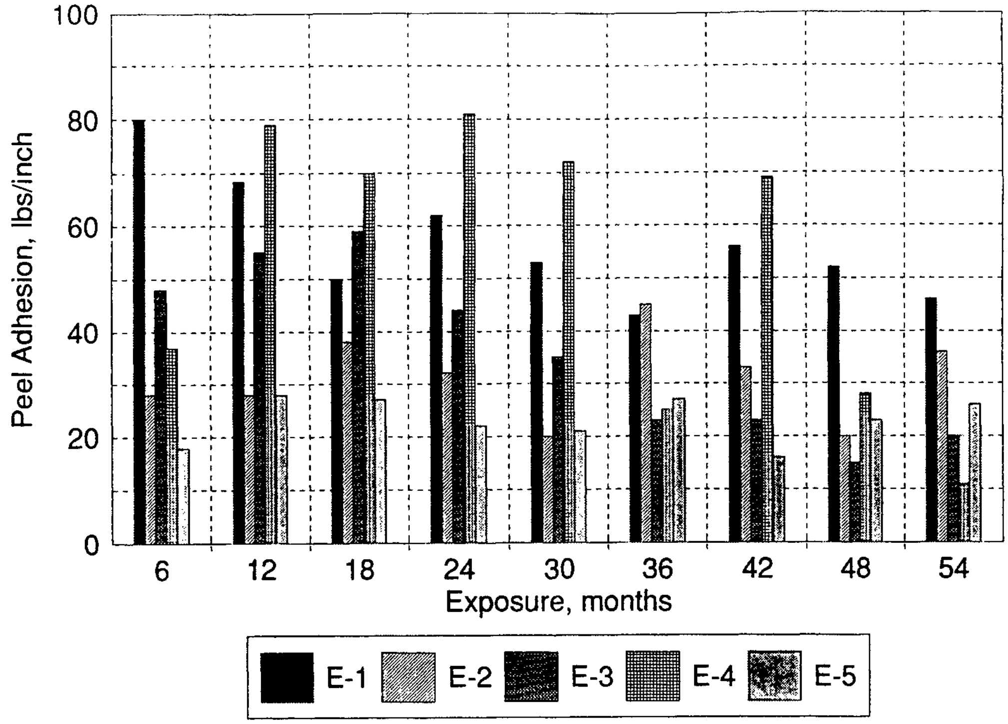

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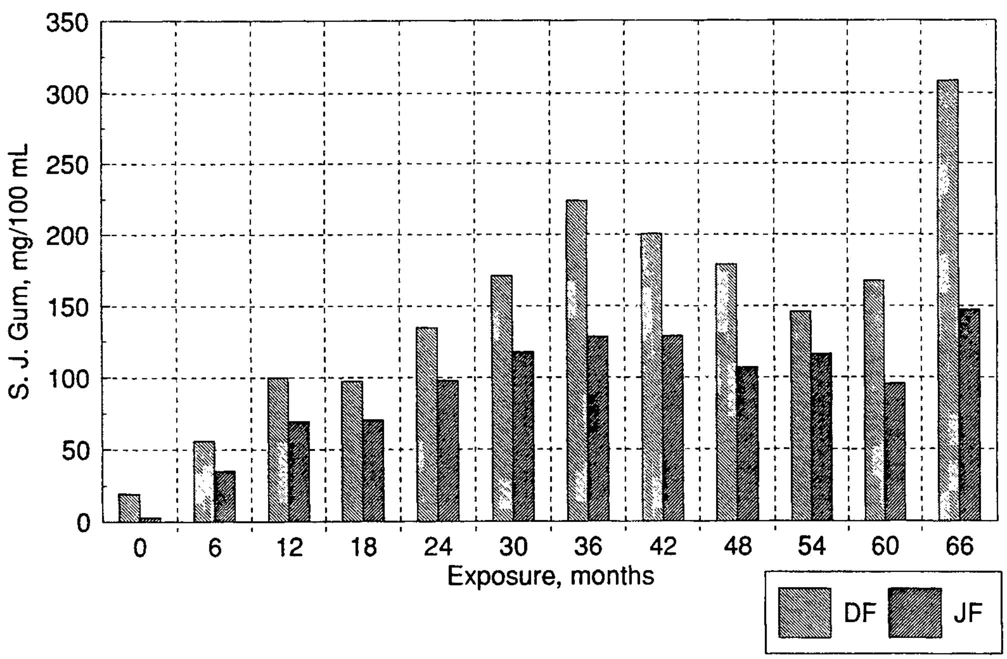

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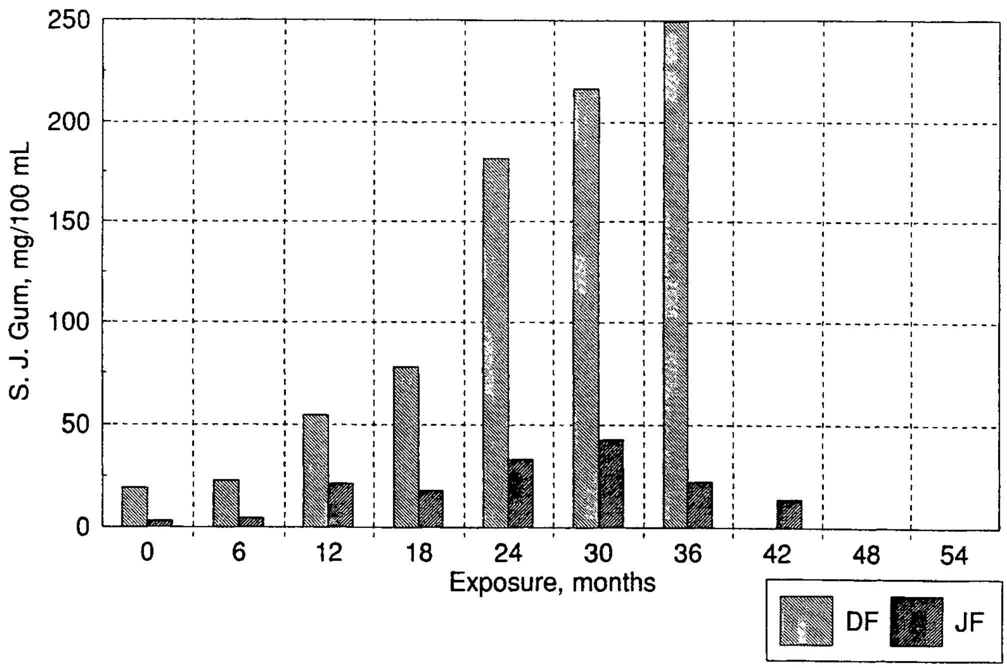

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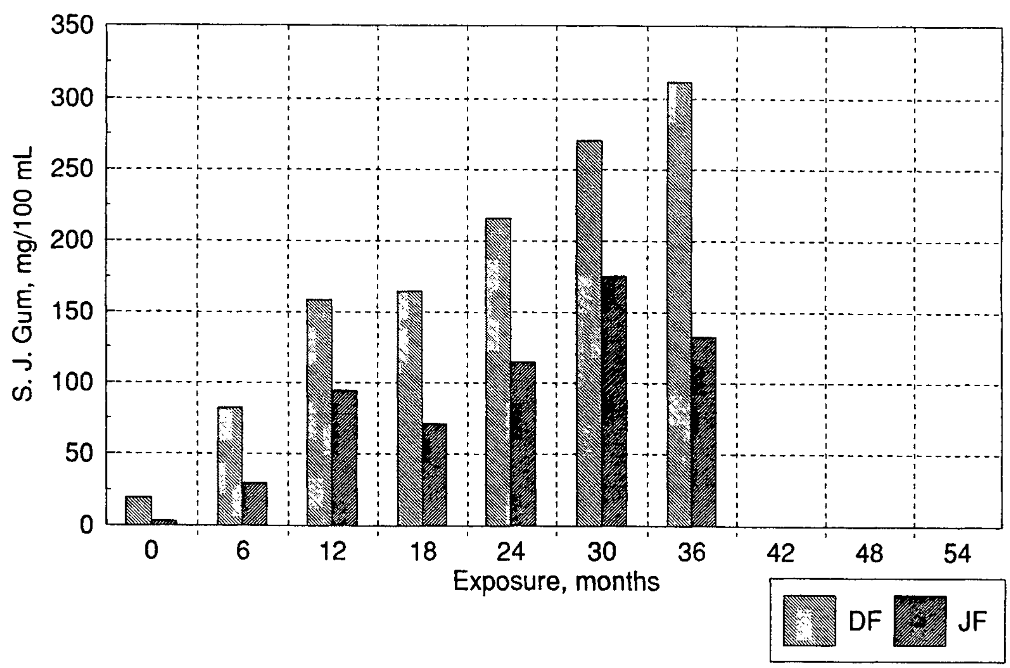

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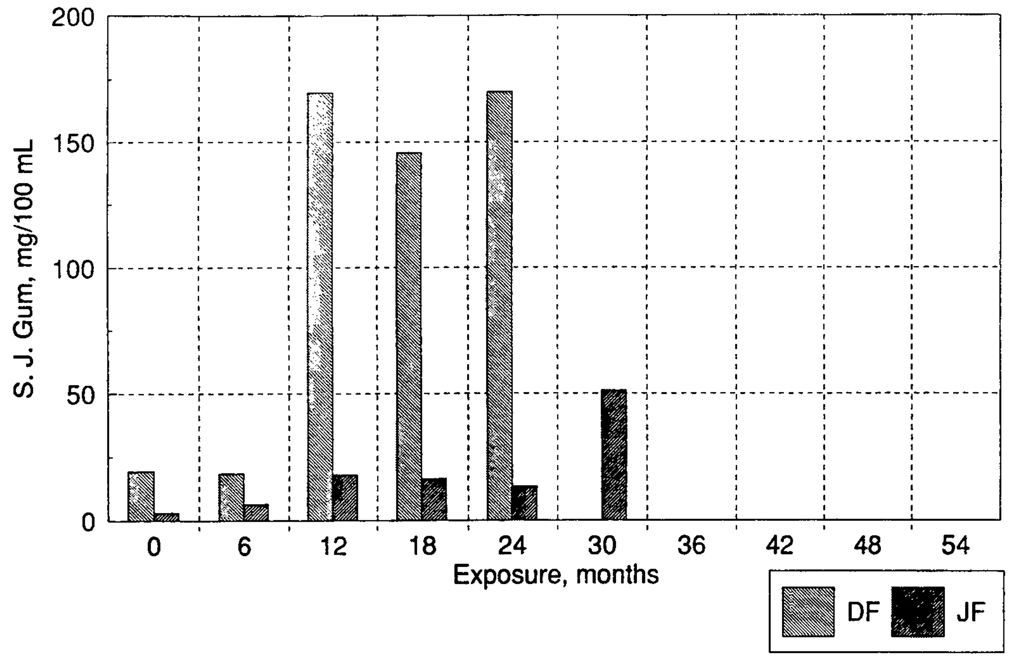

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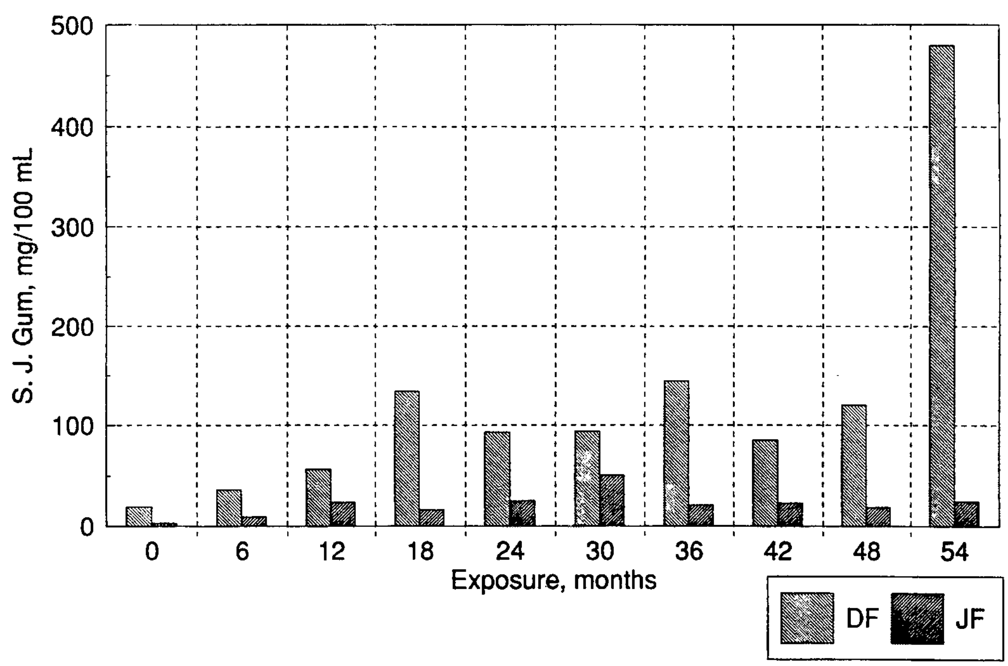

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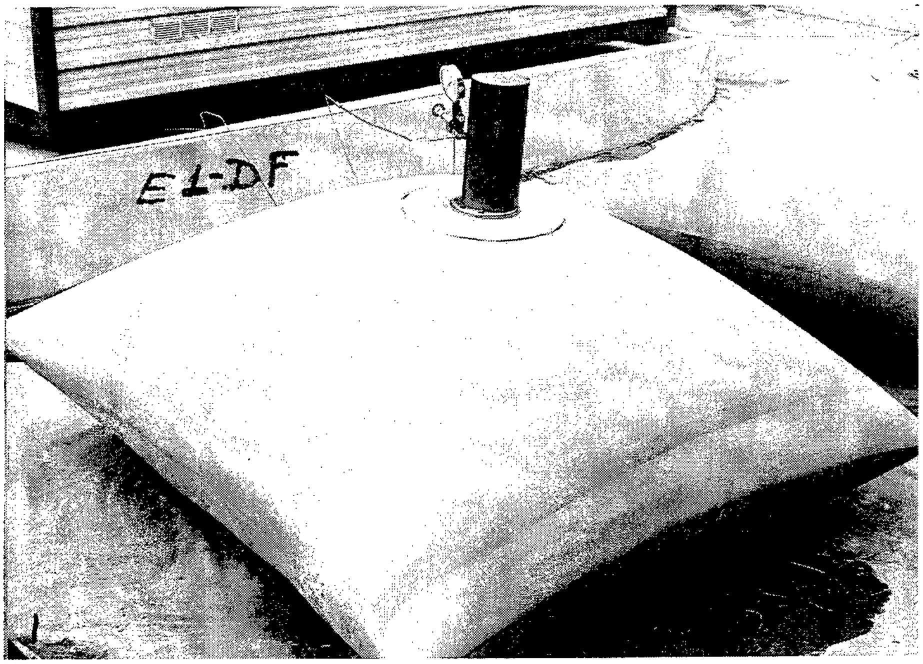

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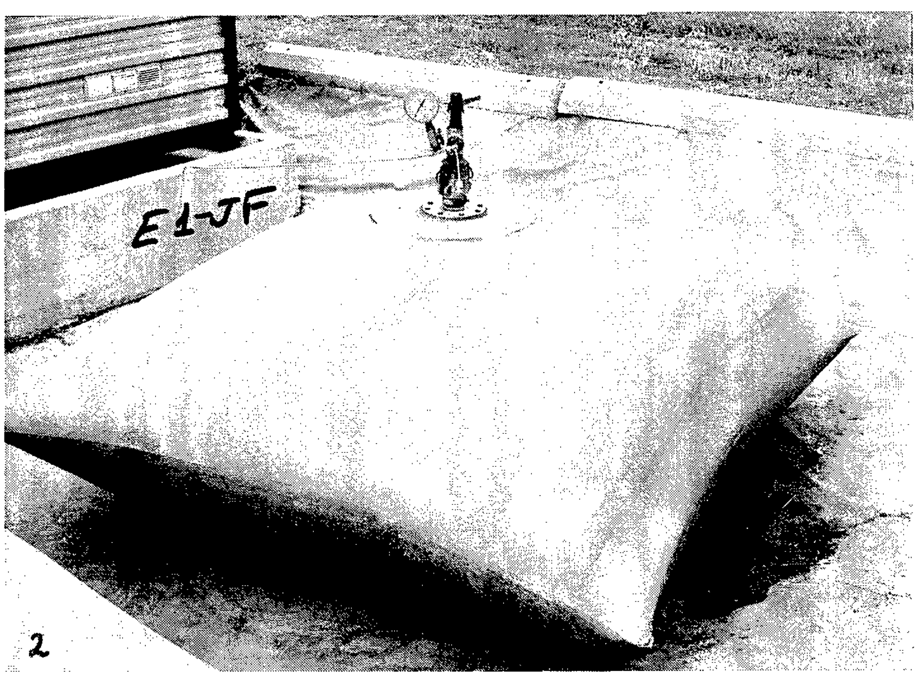

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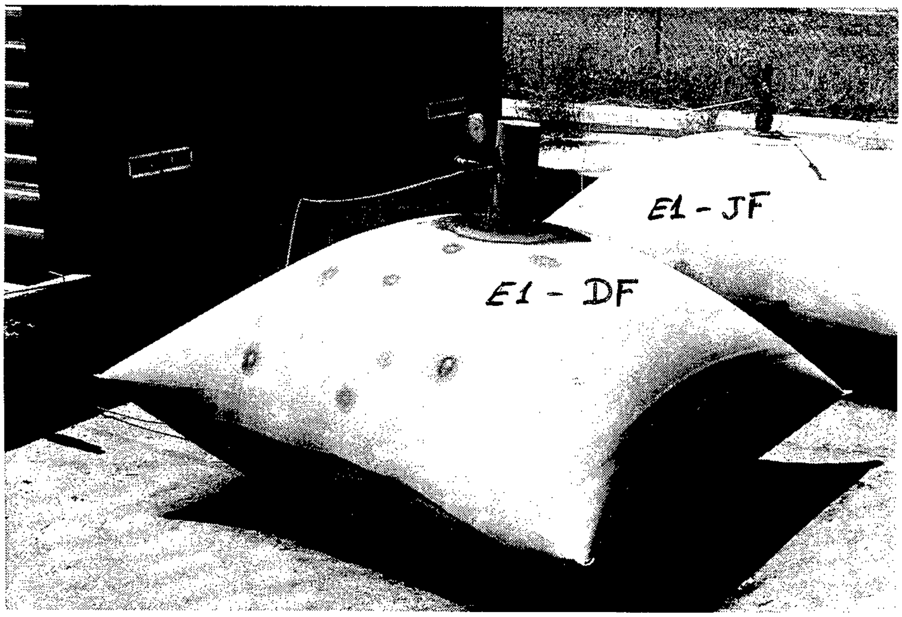

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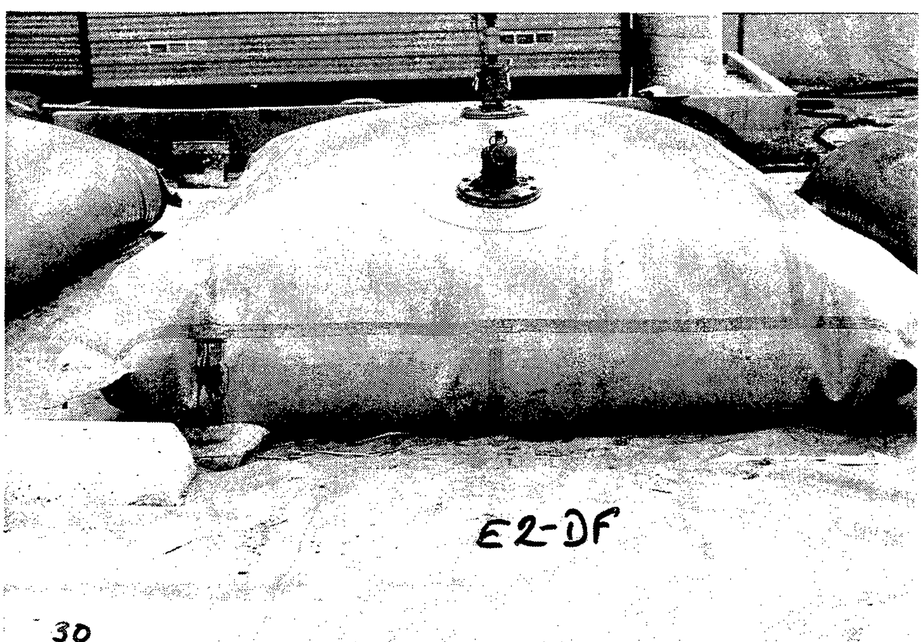

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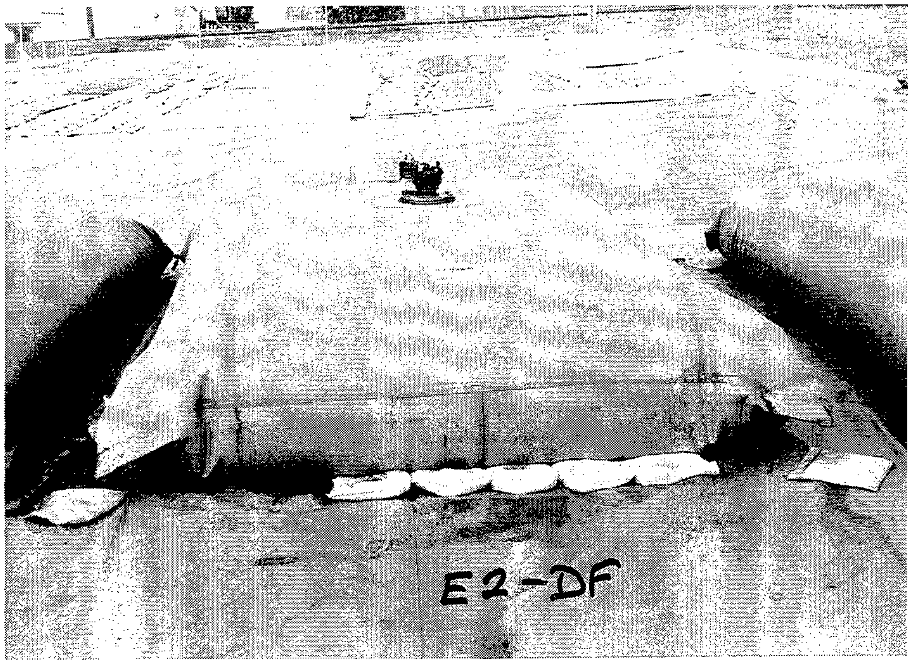

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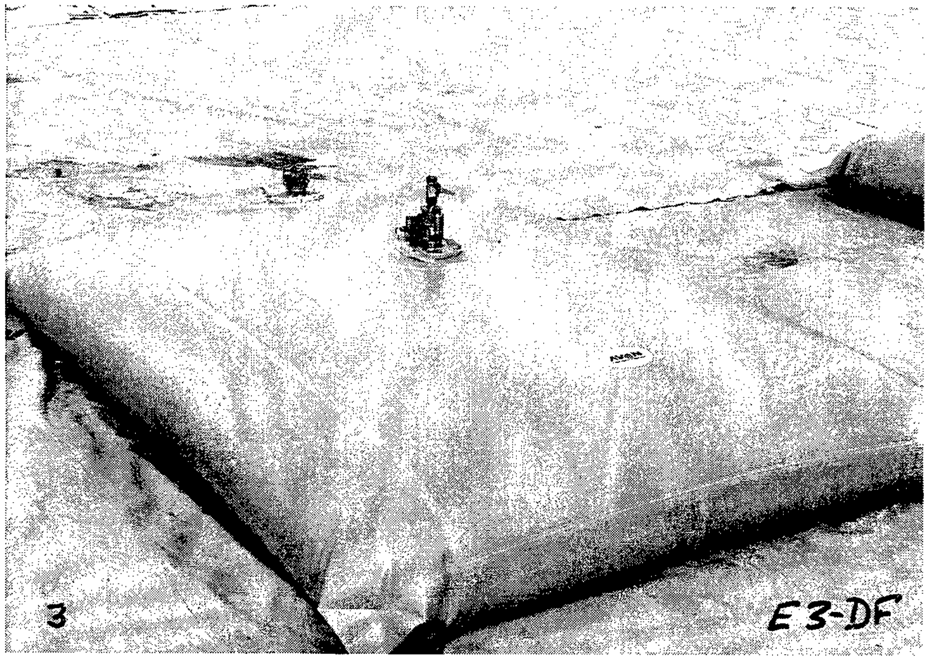

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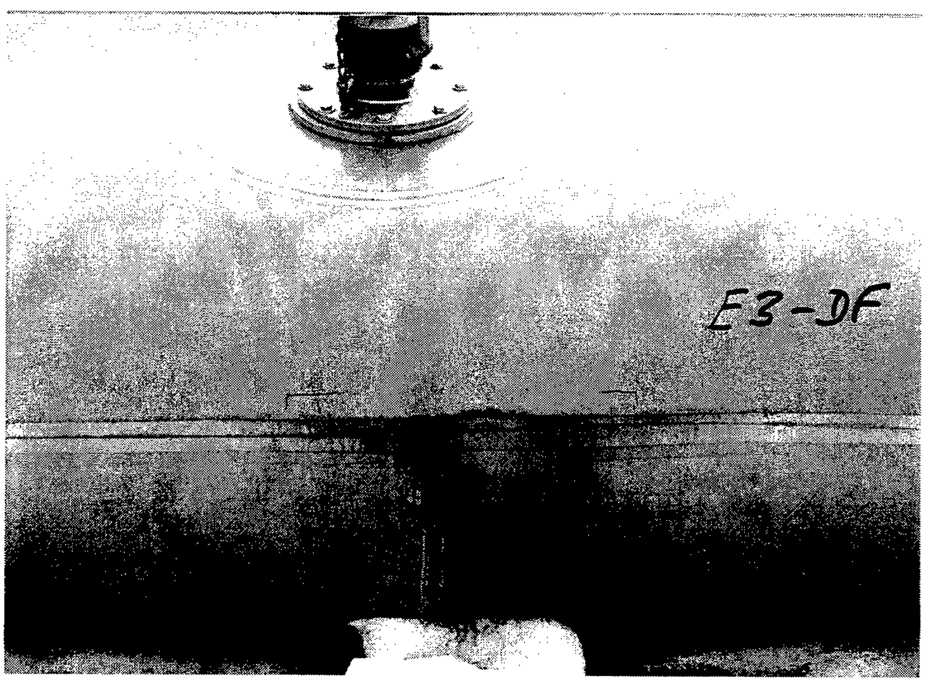

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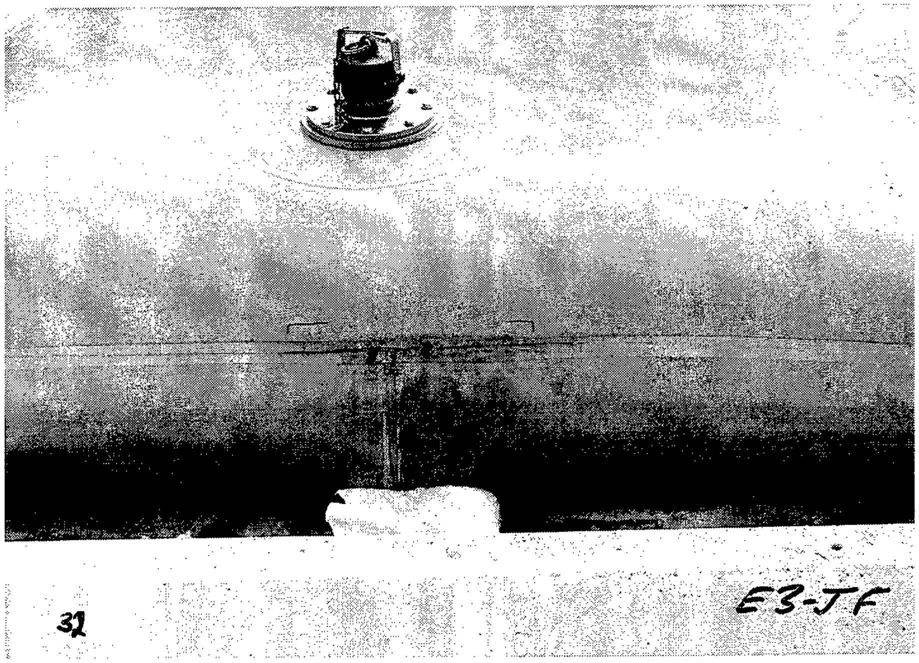

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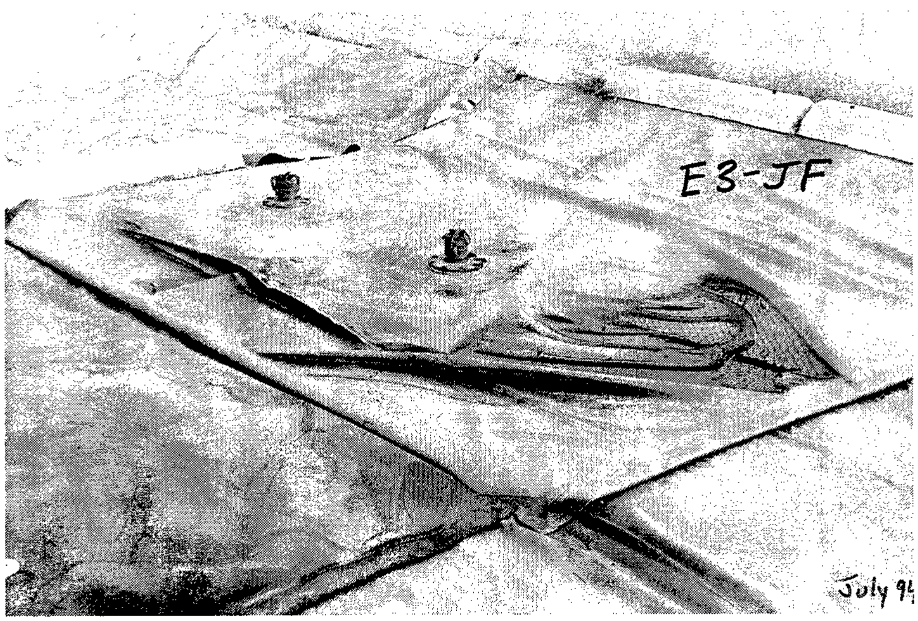

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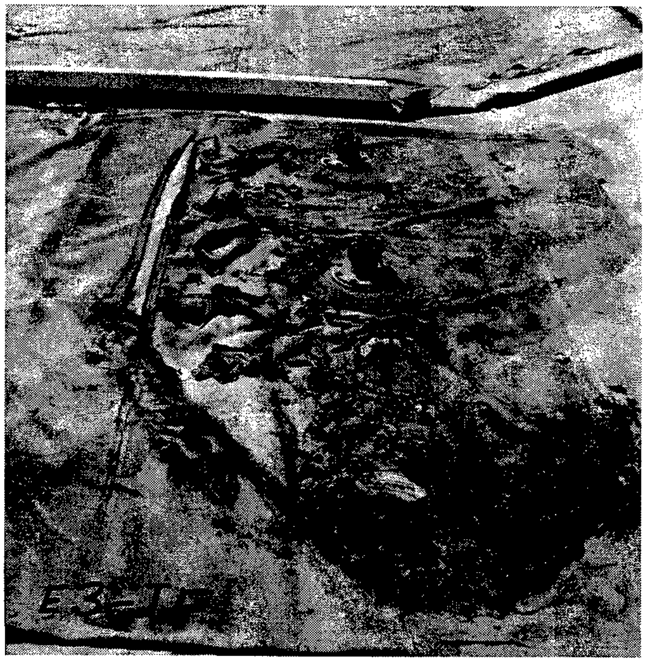

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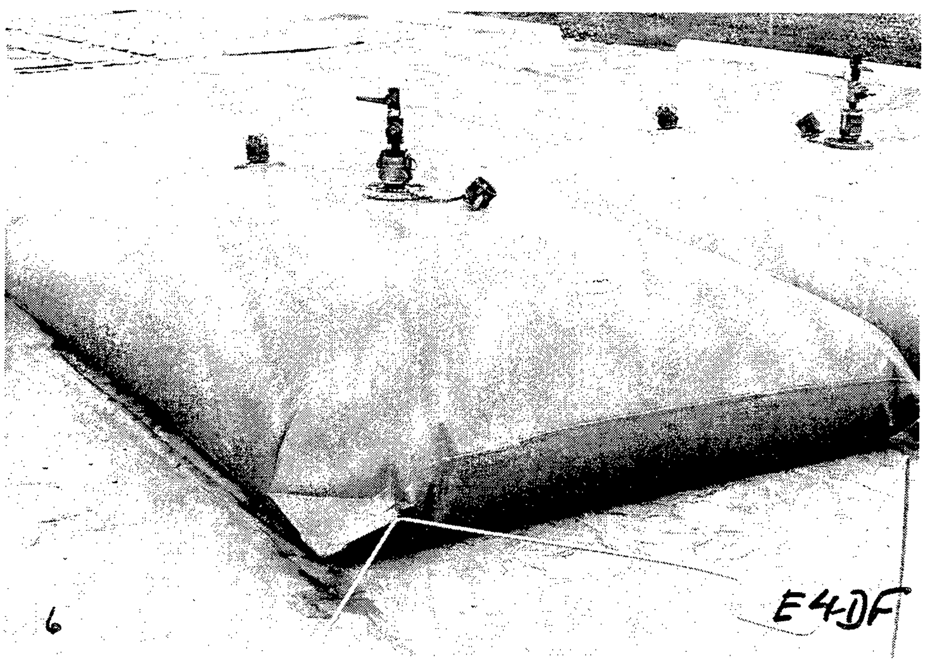

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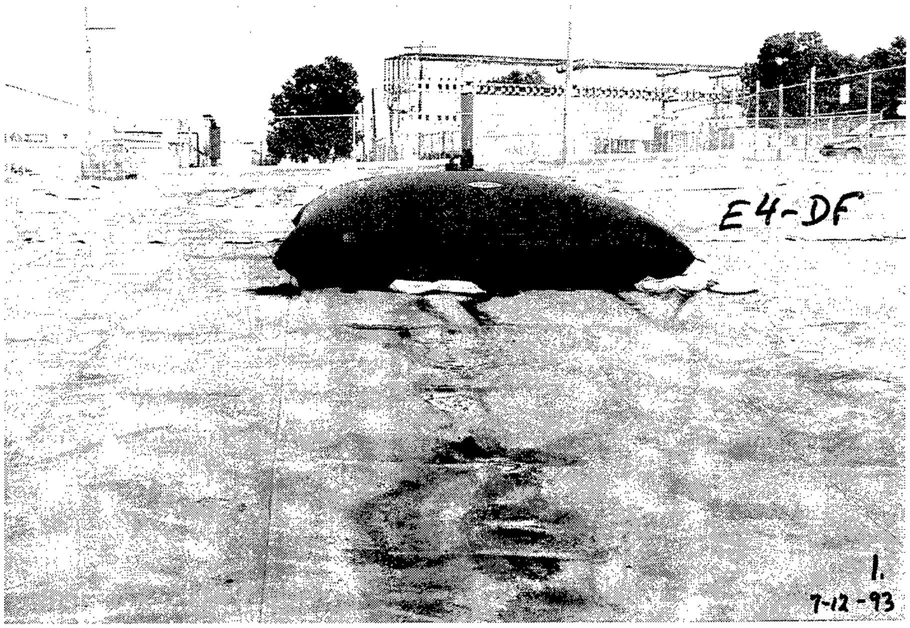

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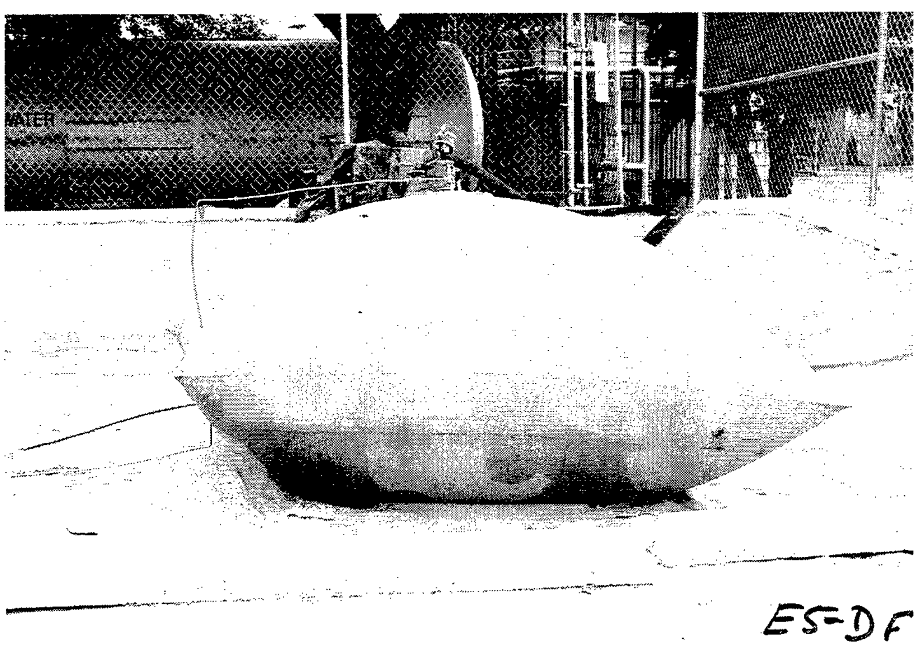
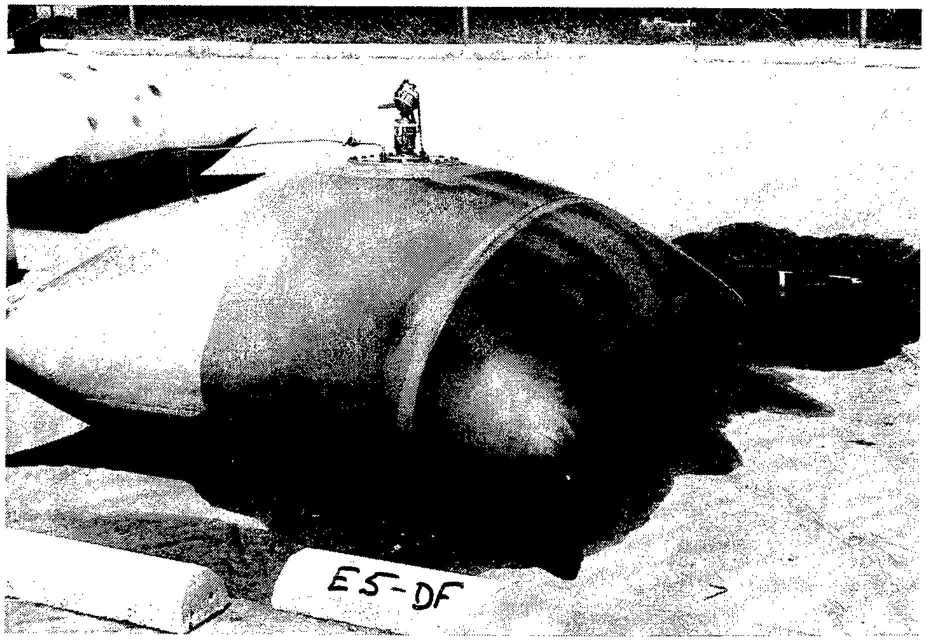
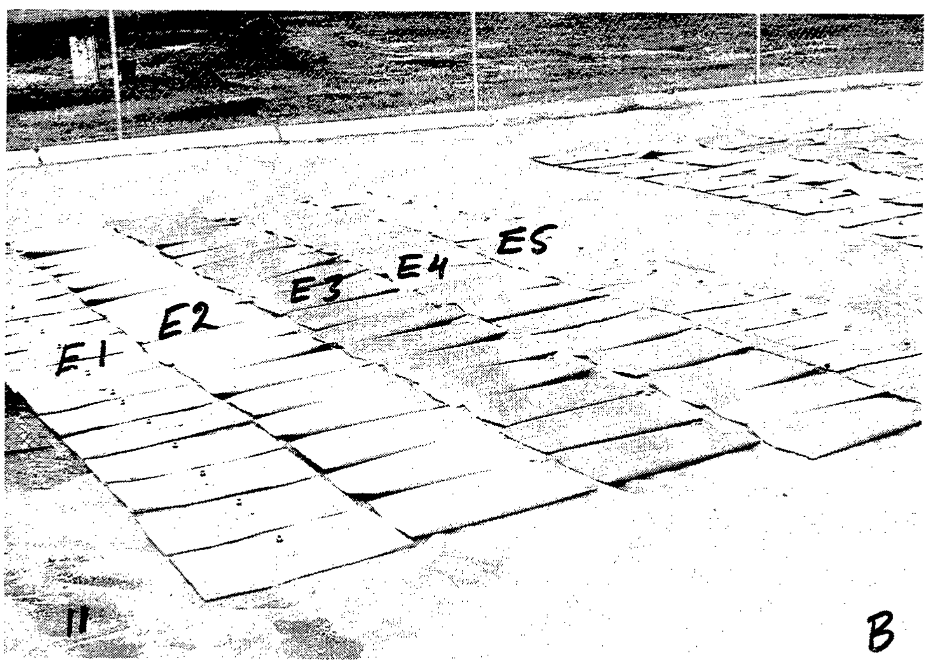


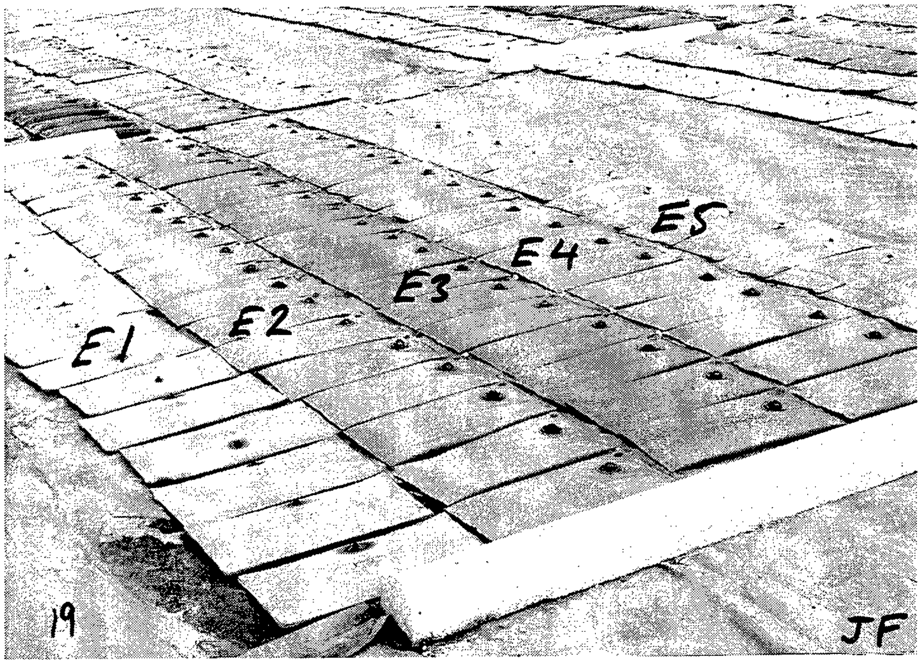
Photograph 14. E-5 minitank filled with diesel fuel one week after tank was placed under test conditions



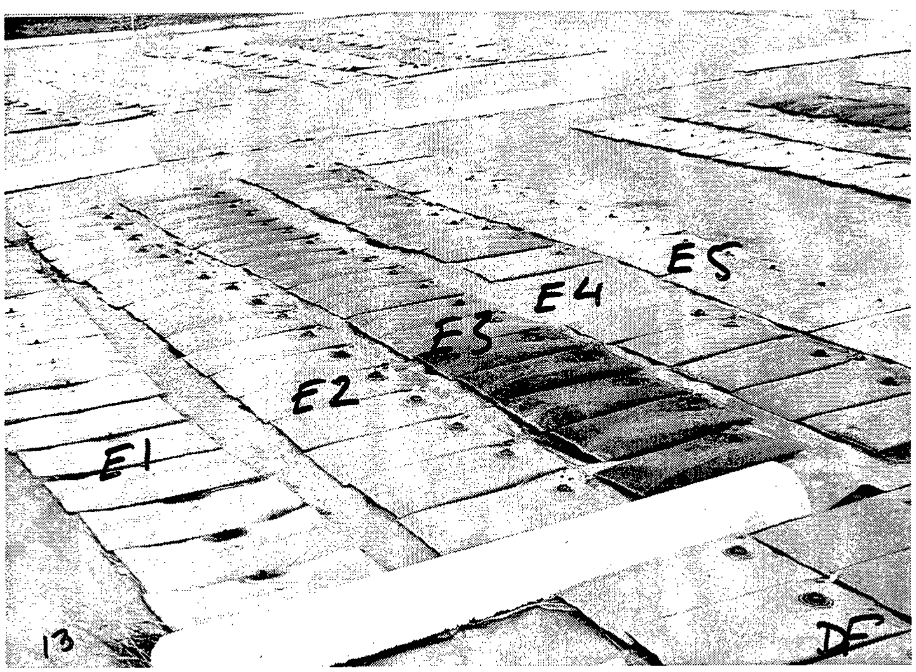
Photograph 15. Evidence of diesel fuel leakage from E-5 minitank



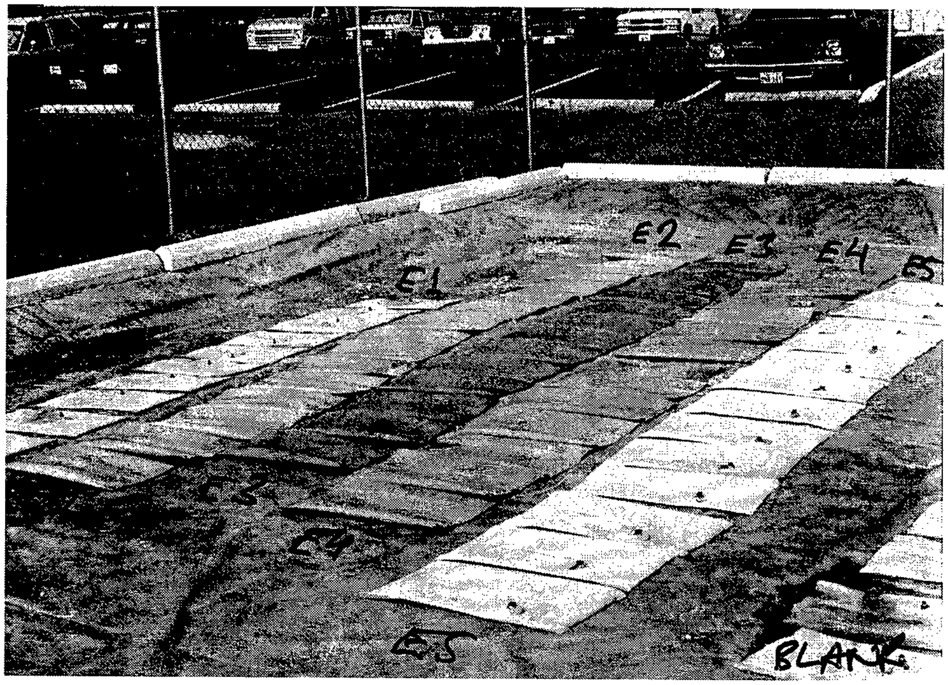
Photograph 16. Empty (blank) sacrificial pillow tanks



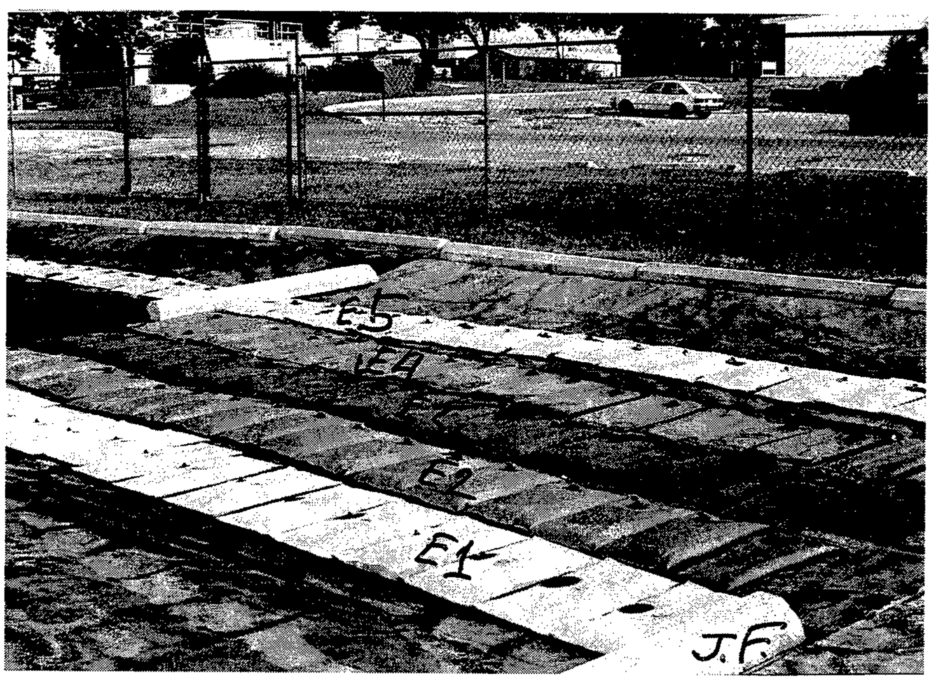
Photograph 17. Turbine fuel-filled sacrificial pillow tanks



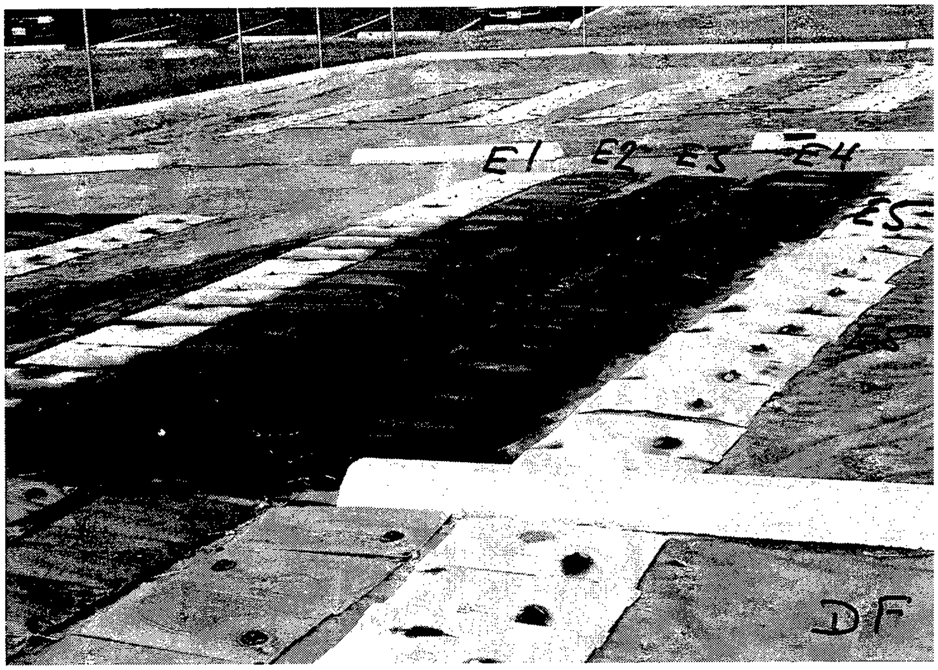
Photograph 18. Diesel fuel-filled sacrificial pillow tanks



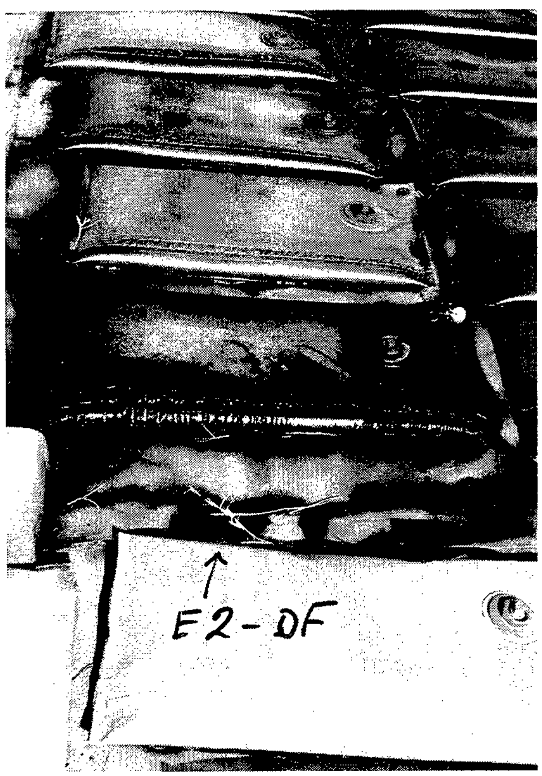
Photograph 19. __Empty (blank) sacrificial pillow tanks two years after deployment__



Photograph 20. __Turbine fuel-filled sacrificial pillow tanks two years after deployment__



Photograph 21. Diesel fuel-filled sacrificial pillow tanks two years after deployment



Photograph 22. Evidence of delamination of the coating polymer from the nylon fabric of an E-2 sacrificial pillow tank containing diesel fuel

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